# A Brief History of BDCP 'Water Operations Waypoints' to Inform Selection of an Adaptive Range

*5-Agency Adaptive Range Technical Team, December 2011*

## *What is the role of this Technical Team?*

It is the intent of the BDCP to include a range of criteria for water operations under a dual conveyance system that, in combination with the conservation measures set out in the Plan, meets the requirements of the ESA and NCCPA. As part of the BDCP adaptive management program, adjustments to the water operations criteria described in Conservation Measure 1 ("CM1") will likely be necessary and advisable. This "adaptive range" of water operations will contribute to the operational and institutional flexibility needed to respond to changed circumstances and unforeseen biological outcomes and will improve the effectiveness of the BDCP over time.[1] Thus, the adaptive range is envisioned as one of several tools built into the BDCP to provide a degree of assurance that the project will attain both its water supply and species protection goals.

The development of an adaptive range for water operations is important to the completion of the effects analysis, the HCP/NCCP, and other aspects of BDCP implementation. This document was produced by staff from DFG, FWS, Reclamation, DWR and NMFS based on an extensive review of scientific literature, previously and currently proposed operational criteria, effects modeling and other analytical information. This report follows the current BDCP effort by summarizing the adaptive range for water operations assuming dual conveyance infrastructure. This effort did not include the development of adaptive management parameters for "other stressors" or habitat restoration conservation measures, and did not cover all of the issues, conservation measures, or available science that BDCP intends to evaluate. Evaluation of other stressors and habitat restoration will be the focus of future discussions on the Adaptive Management Implementation Plan. This document was developed using the following guidance:

1. *Develop adaptive ranges for operational criteria based upon the best available science*. The Team accomplished this by summarizing the extensive scientific literature on the Bay-Delta and its watershed.

2. *Consider scientific uncertainty and changing future conditions over the anticipated 50-year life of the permit. A high level of uncertainty may require a broader range while greater certainty may lead to a narrow range*. The Team accomplished this, as well as bullets 3-4, by providing a full accounting of previous and current proposals. By default, this results in a highly flexible range of potential options that can be narrowed as new tools and information allow.

3. *One end of the adaptive range (Endpoint 2) should focus on describing operations that address the possibility of a significant decline in the viability of covered aquatic species*.

4. *The other end of the range (Endpoint 1) should focus on describing operations that address the possibility of a significant increase in the viability of covered aquatic species*.

---

[1] The adaptive range for water operations is distinct from the concept of "real-time" operations. Real-time operational decisions involve relatively minor adjustments to operations within the criteria set out in CM1.

5. *Consider analyses and modeling assumptions and results from existing efforts, including preliminary Alternatives developed for the EIR/EIS, Scenario #6 developed as part of addressing the "Big 6" issues, Points of Agreement, Ranges A and B from the BDCP Steering Committee's January 2010 Initial Project Operations, the changed circumstances and conservation measures sections of the draft BDCP document and the draft BDCP Effects Analysis*. The Team accomplished this by extensively summarizing model outputs in tables and graphs that provide the reader with the necessary context to inform their decision processes.

The Team responded to its charge by providing this summary of BDCP 'waypoints'. By waypoints, we mean the various river flow targets and other operational criteria that have been developed during the past four years of the BDCP planning. It is our intent that the water operations waypoints be viewed as an 'adaptive menu' of possible operations from which modeling and adaptive management experiments can be designed to inform current and future policy decisions. The report also summarizes the endpoints identified in this report for key water operations parameters (Table 1). The endpoints are the most extreme waypoints for each operations rule that the Technical Team found or developed during its review.

For the most part, the individual waypoints come from existing proposals for which a documented rationale has been previously proposed regarding covered species or habitat responses. Those waypoints that did not have an existing documented rationale were thoroughly discussed and agreed upon by the Technical Team. As such, the waypoints provide guidance for exploring the uncertainty around species' responses to the water operations parameters. The authors of this report do not anticipate, or see the utility in, treating the full suite of endpoints as a BDCP "alternative". By extension, we see no utility in modeling or conducting an effects analysis on either collection of endpoints. Doing so would likely be imprudently risky to species or costly to water supply. It is far more likely that a small number of parameters would be adjusted at any given time in an attempt to either provide additional protection to a species, or to relax restrictions in response to new information about the biological importance of a parameter. Finally, the mere identification of endpoints in this report infers nothing about when, how often, and to what extent any individual endpoint would ever be employed during the permitted life of the BDCP. Specific decisions regarding adaptive ranges are properly within the purview of an adaptive management plan and process linked to program goals and objectives, all of which are still under development.

We start with a brief background on the biology of the BDCP target fishes and then describe the evolution of technical thinking on how to model flow criteria that may meet the needs of all eleven BDCP target fish taxa. The BDCP geographic area is focused on the legal Delta, Yolo Bypass, and Suisun Marsh. Thus, the water operations criteria we review here are likewise focused on these areas. We assumed that the North Delta Diversions would have a 15,000 cfs capacity, and would be screened to meet the NMFS and CDFG fish screen criteria and USFWS fish screen recommendations.

**Table 1. BDCP Adaptive Range for Water Operations End Points.**

| Region | Operations Criterion | End Point 1 | | End Point 2 |
|---|---|---|---|---|
| **North Delta** | NDD Constant Low-Level Pumping | 10% of Freeport flows diverted | Intermediate waypoints | 2% of Freeport flows diverted |
| | NDD Initial Pulse Protection | No initial pulse protection | | *Requires further discussion* |
| | NDD Bypass Flows | Level III pumping throughout the year | | Level I pumping throughout the year |
| | Fremont Weir: Yolo Bypass Inundation Flows | *Defer to OCAP technical group* | | *Defer to OCAP technical group* |
| | Fremont Weir: Adult Fish Passage Flows | 100 cfs | | 1000 cfs |
| | Delta Cross Channel Operations | 0% open Jan-Jun; 100% open Jul-Sep, Dec; 100% open Oct-Nov | | 0% open Dec-Jun; 100% open Jul-Sep; 0% open Oct-Nov |
| **South Delta** | Old and Middle River Flows | -9000 cfs (Jan-Mar); -6100 cfs (Apr-Jun); No limit (Jul-Nov); -10,000 cfs (Dec) | | 1000 cfs (Dec-Mar); No South Delta exports (Apr-Jun, Oct-Nov); -2000 cfs (July-Sept) |
| | Summertime Exports (North vs. South Delta Preference) | 100% North or 100% South | | 100% North or 100% South |
| | Fall San Joaquin Pulse Flow Protection (Oct-Nov) | D-1641 flows; no South Delta export limit | | D-1641 flows; no South Delta exports |
| | Operable Head of Old River Barrier | 100% open year round | | 0% open year round except Jul-Sept, Dec |
| **Delta-Wide Indicators** | Fall Delta Outflow (Sept-Nov) | No USFWS RPA | | To be determined |
| | Spring Delta Outflow (Feb-Jun) | D-1641 criteria (except Roe Island standard) | | Eight-River Index X2 |
| **Methodology** | Total Export:Total Inflow (D-1641 Standard) | As calculated by preliminary proposal | | As calculated with all inflows to the legal Delta and all exports |

*What are the BDCP target fishes and how are they influenced by Water Project operations?*

There are eleven species, Evolutionarily Significant Units (ESUs), or Distinct Population Segments (DPSs) of fishes that are target species in the BDCP. Brief summaries of their biology and population drivers are provided in Table 2.

The Sacramento River basin generally supports native fishes better than the San Joaquin River basin due to differences in water management strategies (May and Brown 2002; Brown and Moyle 2005). The Sacramento River and its major tributaries are largely used as a water conveyance system. Stored water is released during summer months, which keeps water temperatures cooler downriver of the dams. The cool summer water temperatures in these upriver areas are critical to maintaining winter-run Chinook salmon viability given its very limited spawning distribution (NMFS 2009), but cool temperatures also help maintain other salmonid and non-salmonid native fishes elsewhere in the basin (Marchetti and Moyle 2001; May and Brown 2002; Seesholz et al. 2004; NMFS 2009). Note that in the relatively unregulated Cosumnes River, where summer water temperatures are warm and base flows are low, non-native species like redeye bass have displaced the native stream fishes (Moyle et al. 2003). This is a very similar biotic outcome to what has been observed in the regulated streams of the San Joaquin River basin where stored water is diverted out of the channels and reservoirs leaving low flow, warm water conditions prevalent in many locations during summer (Brown 2000; Brown and Moyle 2005).

In the Delta, water temperatures are influenced mainly by air temperature. Tidal dispersion and river flows play lesser roles (Wagner at al. 2011, Monismith et. al 2009); only flow extremes measurably affect water temperatures in the Delta (Kimmerer 2004; Wagner et al. 2011). The native fish assemblages of Suisun Marsh and the Delta are also being displaced by non-native fishes, but this trend is likely due to more than just summer water temperatures; other water quality and food web changes are involved as well (Matern et al. 2002; Brown and Michniuk 2007; Moyle and Bennett 2008; Mac Nally et al. 2010). The seasonal flooding of the Yolo and Sutter bypasses provides an important spawning and rearing habitat for a few native fishes (Sommer et al. 2001a; Feyrer et al. 2006a), but these floodplains are not extensively available every year, nor do they provide a demonstrable benefit to all BDCP target species (Table 2).

**Table 2. Life-history summaries of the BDCP target fishes. Except where noted in the footnote, the statements made are cited to Moyle (2002) and references therein.**

| *Species or ESU* | *Spawning Habitat* | *Use of the Delta and Yolo Bypass* | *Major population dynamic drivers* |
|---|---|---|---|
| Pacific lamprey | Nest-builder in cobble/gravel substrata in shallow water; spawn in numerous locations in the watershed during spring. | Migratory corridor; winter-spring. | Unknown. Possibly limited by amount of rearing habitat and macropthalmia survival. |
| River lamprey | Nest-builder in cobble/gravel substrata in shallow water; spawn in numerous locations in the watershed during spring. | Migratory corridor; winter-spring (juveniles) and fall (adults). | Unknown. Possibly limited by amount of rearing habitat and macropthalmia survival. |
| White sturgeon | Cobble/gravel substrata in deep water pools during spring; mainly Sacramento River from Knights Landing to several km above Colusa. | Some migratory individuals; most stay in estuary; migratory corridor in winter-spring; rearing habitat year-around. | Good recruitment linked to high flows during spring[1]; adult population very sensitive to mortality rates. |
| Green sturgeon | Cobble/gravel substrata in deep water pools during spring-summer. Spawning occurs in the Sacramento River from above Hamilton City to above the RBDD and possibly as far upstream as Keswick Dam[2]. | More strongly marine oriented than white sturgeon[3]; migratory corridor in spring and early summer; rearing habitat year-round[4]. | Poor recruitment linked to low flows during spring[5]; Adults very sensitive to mortality rates[3]; only known spawning locations are the Sacramento River and the Feather River for the Southern DPS[6,7]. |
| Fall/late-fall-run Chinook salmon | Nest-builder in cobble/gravel substrata in shallow water; spawn in numerous locations in the watershed during | Adult migratory corridor during the fall; juvenile rearing habitat and migratory corridor during winter-spring; | Inland survival linked to river flows[9,10]; known juvenile food limitation prior to ocean entry – but not known to be |

| | | | |
|---|---|---|---|
| | fall-early winter; late fall-run spawns during winter. | Yolo Bypass likely an important rearing habitat and juvenile corridor when flooded[8,9]; known to also rear in Suisun Marsh and San Francisco Bay, but dependent on river and Delta outflow conditions[10]. | lethal[8,13]; food limitation can be lethal (or lead to elevated predation loss) upon entry to the marine environment if ocean productivity is low[14]. |
| Spring-run Chinook salmon | Nest-builder in cobble/gravel substrata in shallow water; spawn in several locations in the Sacramento River watershed during fall. | Adult migratory corridor during the spring; potential juvenile rearing habitat and migratory corridor during winter-spring. | Likely similar drivers to fall-run; adult inland survival also linked to summer water temperatures in stream reaches where adults attempt to over-summer[15]. |
| Winter-run Chinook salmon | Nest-builder in cobble/gravel substrata in shallow water; spawn in upper reaches of Sacramento River below Keswick Dam. | Adult migratory corridor during the winter; juvenile rearing habitat and migratory corridor during winter-spring; Yolo Bypass likely an important rearing habitat and juvenile corridor when flooded[16]. | Spawn late spring-summer, so inland survival strongly linked to summer water temperatures in the upper Sacramento River[17]; survival likely also linked to river flows and ocean productivity[14]. |
| Steelhead | Nest-builder in cobble/gravel substrata in shallow water; spawn in numerous locations in the watershed during winter (Dec-April). | Adult migratory corridor during fall-winter[18]; juvenile migratory corridor and possible rearing habitat during winter-spring[19]; not known to use Yolo Bypass[20] or Suisun Marsh[21] to any substantive extent. | Smolt survival limiting factor on anadromous life-history expression[22]. Spend 1-2 years in spawning streams, many of which have stressful summer temperatures[18]; passage of adults and smolts is a major problem on many rivers. |
| Longfin smelt | Not known for SFE population; likely broadcast spawner over sand-gravel substrata near or within the LSZ during winter[23]. | Spawning habitat; larval rearing habitat; some individuals historically remained within the upper estuary, but this is uncommon now[24]; | Recruitment linked to Delta outflow during early life stages and food limitation[24,25]; use of upper estuary as a contingent juvenile |

| | | | |
|---|---|---|---|
| | | not known to use Yolo Bypass to any substantive extent[20]; historically used Suisun Marsh extensively[24]. | habitat limited by warm summer temperatures, low turbidity, and low food supply (mysids)[26]; note that food limitation most likely occurs during summer – thus, Yolo Bypass cannot contribute meaningfully to improving food supply for longfin smelt. |
| Delta smelt | Not known; likely broadcast spawner over sand-gravel substrata near the LSZ during spring. | All individuals complete their life cycle in the upper estuary including the Delta; known to use Liberty Island in the lower Yolo Bypass and Montezuma Slough in Suisun Marsh extensively[27]. | Unknown, but linked to cumulative changes in the estuary's low-salinity zone[28]; entrainment risk, high summer temperatures, food limitation, low turbidity, seasonally low habitat suitability etc. |
| Splittail | Broadcast spawner on submerged vegetation along river margins and in floodplains. | Rearing habitat and migratory corridor for adults and juveniles of the Central Valley population; known to use Yolo Bypass and Suisun Marsh extensively[29]. | Recruitment linked to extended floodplain inundation during spring[30]; known food limitation[31], but population dynamic consequence is unknown. |



[1]Fish (2010); [2]Heublein et al. (2009);; [3]Lindley et al. (2008); [4]Lindley et al. (2011); [5] Poytress et al. (2009); [6]Adams et al. (2007); [7]Alicia Seesholtz (CDWR, pers. comm.);[8]Sommer et al. (2001); [9]Sommer et al. (2005); [10]Brandes and McLain (2001); [11]Kjelson and Brandes (1989); [12]Newman (2003); [13]MacFarlane et al. (2002); [14]Lindley et al. (2009); [15]Williams (2006); [16]NMFS (unpublished data); [17] Noble Hendrix (unpublished data); [18]McEwan (2001); [19]Nobriga and Cadrett (2001); [20]Feyrer et al. (2006a); [21]Matern et al. (2002); [22]Satterthwaite et al. (2010); [23]DFG (2009); [24]Rosenfield and Baxter (2007); [25]Kimmerer (2002b); [26]Baxter et al. (2010); [27]DFG Spring Kodiak Trawl and 20-mm Survey websites (www.dfg.ca.gov/delta/); [28]Bennett (2005); [29]Moyle et al. (2004); [30]Sommer et al. (1997); [31]Greenfield et al. (2008)

*What Water Operations Waypoints did the Technical Team consider?*

The BDCP is focused on Sacramento River inflows to the Delta and flows at various locations within and out of the Delta. It does not address the management of inflows from the San Joaquin River basin (including east-side tributaries). The water operations waypoints considered by the Adaptive Range Technical Team and the species and life-stages they may influence are listed in Table 3.

**Table 3. Water Operations criteria evaluated by the Adaptive Range Technical Team.**

| *Region* | *Operations criterion* | *Species and life stage(s) addressed* |
|---|---|---|
| **North Delta** | North Delta diversion bypass flows | Survival of all juvenile salmonids and sturgeon; possibly survival of juvenile splittail, lampreys, and migrating adult delta smelt. |
| | Protection of Sacramento River pulse flows (magnitude and duration) | Survival of all juvenile salmonids and sturgeon; possibly survival of juvenile splittail and lampreys. |
| | Rio Vista flows | Likely survival of juvenile salmonids; larval survival of longfin smelt; delta smelt and splittail rearing habitat suitability; possibly adult salmonid and sturgeon attraction flows. |
| | Fremont Weir flows | Splittail attraction flows and spawning success; juvenile Chinook salmon survival and rearing habitat suitability; larval food supply for delta smelt inhabiting Cache Slough region; false attraction flows for adult salmonids, sturgeon, and lampreys; bioaccumulation of methyl mercury in fish and their predators. |
| | Delta Cross Channel Operations | Survival of juvenile Sacramento River Basin Chinook salmon/ straying of adult Mokelumne River salmonids, maintenance of water quality standards in the interior Delta. |
| **South Delta** | Old and Middle River flows | Entrainment risk for all species in Table 2, but most strongly for smelts and San Joaquin Basin salmonids. |
| | D-1641 fall pulse flow on the San Joaquin River | San Joaquin River fall-run Chinook salmon attraction flows; small additional influence on fall habitat suitability for delta smelt. |
| | Operable Head of Old River Barrier | Survival of juvenile San Joaquin |

| | | |
|---|---|---|
| | | River salmonids and possibly splittail spawned in the SJR; homing of adult salmon during the fall. |
| | South Delta export rates | Entrainment risk for all species in Table 2, but most strongly for smelts and San Joaquin basin salmonids; attraction flows for San Joaquin basin fall-run Chinook salmon. |
| **Delta-wide indicators** | Delta outflow ($X_2$) | Survival and estuarine habitat suitability of all species listed in Table 2. |
| | Export:SJR flow | Survival of juvenile San Joaquin River basin salmonids and possibly splittail. |
| | Total Export:Total Inflow | Survival and estuarine habitat suitability of all species listed in Table 2. |

***Rationale for North Delta Diversion Bypass Flows***: All of the BDCP target fishes that spawn in the Sacramento River or its tributaries upstream of the North Delta diversions have young that need to pass the diversions. The goals of the North Delta Diversion bypass (NDDB) flows are to assure successful fish migration past the proposed intakes and to contribute to habitat suitability in the Sacramento River downstream of the structures. Fish screen design is a second key part of successfully passing young fish; this is being addressed by the Fish Facilities Technical Team. However, we also expect fish passage to be affected by the magnitude, timing and duration of the NDDB flow criteria. To a much lesser extent, passage will also be affected by Fremont Weir flows that are sometimes high enough to route some juvenile Chinook salmon away from the proposed North Delta diversions, and enable successful splittail production from within the Yolo Bypass.



***Evolution of Technical Expert Thinking About How the North Delta Diversion Bypass Flows Need to Work to Protect the BDCP Target Fishes***: The NDDB flow criteria were initially envisioned as a Sacramento River baseflow just upstream of the proposed diversions, below which no water diversion would occur, and then a gradual increase in allowable diversions when flows could be maintained above the threshold. The baseflow thresholds initially discussed for the period of salmonid fish emigration varied from 9,000 cfs to 20,000 cfs. The baseflow generally agreed upon for the summer months when salmonid fishes are no longer present has consistently been proposed to be 5,000 cfs. Modeling results show that a 9,000 cfs baseflow would substantially reduce historical flow pulses that bring winter-run and other Chinook salmon into the Delta and influence their survival (Perry et al. 2010). Modeling also shows that a 20,000 cfs baseflow would have a large impact on anticipated water supply because it substantially reduces potential water diversion.

More recently, NDDB flow criteria have included a small baseline percentage of flow that can be diverted when flow at Freeport remains above 5,000 cfs. This has been termed “constant low-level pumping”. These recent criteria also include a complex set of rules designed to protect flow pulses on the Sacramento River (sensu Flannery et al. 2002). Table 4 shows the existing constant low-level pumping rates and Sacramento River flows that would occur downstream of the diversions for Freeport flows above 5,000 cfs. Note that we did not find any information to indicate whether the degree of risk to any target fish species differs among these waypoints. However, recent research has shown that alteration of streamflows can have large consequences on the biological communities of the affected watershed. Carlisle et al. (2010) found that in an analysis of over 200 stream systems, “biological assessments showed that, relative to eight chemical and physical covariates, diminished flow magnitudes were the primary predictors of biological integrity for fish and macroinvertebrate communities”. In other words, the change in flow was a better predictor of whether the biotic communities were impaired than variables such as temperature, pH, total nitrogen, or urban land cover. It is also well recognized that streamflow reductions can impair the ecological function of downstream estuaries (Drinkwater and Frank 1994; Jassby et al. 1995; Loneragen 1999; Flannery et al. 2002; Winder et al. 2011).

**Table 4. Various proposed constant low-level pumping rates for proposed North Delta diversions at Freeport flows > 5,000 cfs. The flow that would occur downstream of the diversions if Freeport flow was 5,500 cfs is also shown.**

| ***Model scenario*** | ***Proposed low-level pumping rate*** | ***Downstream flow if Freeport flow = 5,500 cfs*** |
|---|---|---|
| Steering Committee Range B | 2% | 5, 390 cfs |
| EIR/S “Enhanced Aquatic” Alternative 4 | 5% | 5,225 cfs |
| Steering Committee Preliminary Proposalt, Scenario 3[1], and Scenario 6[1] | 6% | 5,170 cfs |
| Steering Committee Range A | 10% | 5,000 cfs |

[1]Details about the operations proposed in this scenario can be found on the BDCP website at: http://bdcpweb.com/Libraries/Active_Working_Groups_v1/5-23-11_Combined_Document-Alternative_Project_Ops.sflb.ashx

The currently proposed NDDB flow criteria also include rules designed to preserve Sacramento River flow pulses that exceed 20,000 cfs. The rationale is that 20,000 cfs is the approximate flow at Freeport needed to improve transport of a portion of early-migrating juvenile winter-run Chinook salmon from Knight’s Landing to Chipps Island (Figure 1) and thereby improve their survival (Del Rosario et al. in review). Flows of this level have also been correlated with consistently high fall-run Chinook salmon smolt survival through the Delta (Kjelson and Brandes 1989).

Minimum NDDB flow criteria have also been proposed to prevent any increase in the percent of time that tidal flow reversals occur at the junction of the Sacramento River and Georgiana Slough. As inflows from the Sacramento River decrease, the percent of time that the tide causes net upstream flows to occur at the junction increases. Recent work (Perry et al. 2010) has shown that juvenile Chinook salmon have a higher probability of entering Georgiana Slough when the instantaneous flow at the junction is in an upstream direction. Several studies (Perry et al. 2010, Newman and Brandes 2010) have shown that survival rates of fish that enter Georgiana Slough are much lower than those that remain in the mainstem Sacramento River. Therefore, one goal of maintaining minimum NDDB flows is to prevent an increase in the percentage of emigrating juvenile fishes that enter the interior Delta. Another proposal called for a non-physical barrier to prevent emigrating Sacramento River fish from migrating into the interior Delta even if flows were reversed. This barrier is still undergoing testing, and its effectiveness at improving survival may still depend on flow conditions at the barrier site.

The difference in resultant NDDB flows between earlier rules and the newer ‘post-pulse protection’ rules can be substantial (Figure 2). In addition to baseflow magnitude, there has been considerable variation in proposals regarding the necessary cumulative duration of flow pulses ≥ 20,000 cfs (Table 5). Winter-run Chinook salmon can spend between six weeks to four months rearing in the Delta, with the majority exiting in March and April (Figure 3). Most fall- and spring-run salmon emigration occurs subsequent to winter-run (i.e., April-June; Kjelson and Brandes 1989; Brandes and McLain 2001; NMFS 2009), which adds another 4-8 weeks (i.e., through June) during which flow quantity and/or pulses are biologically desirable. Thus, the lower end of the three flow pulse duration waypoints presented in Table 5 increases the risk to Chinook salmon survival relative to longer duration proposals. The flow needs of splittail, juvenile sturgeon, and lampreys in the North Delta are not known; however, many juvenile splittail and sturgeon will pass the proposed diversions later than the salmonids (Feyrer et al. 2005; Gaines and Martin 2001).

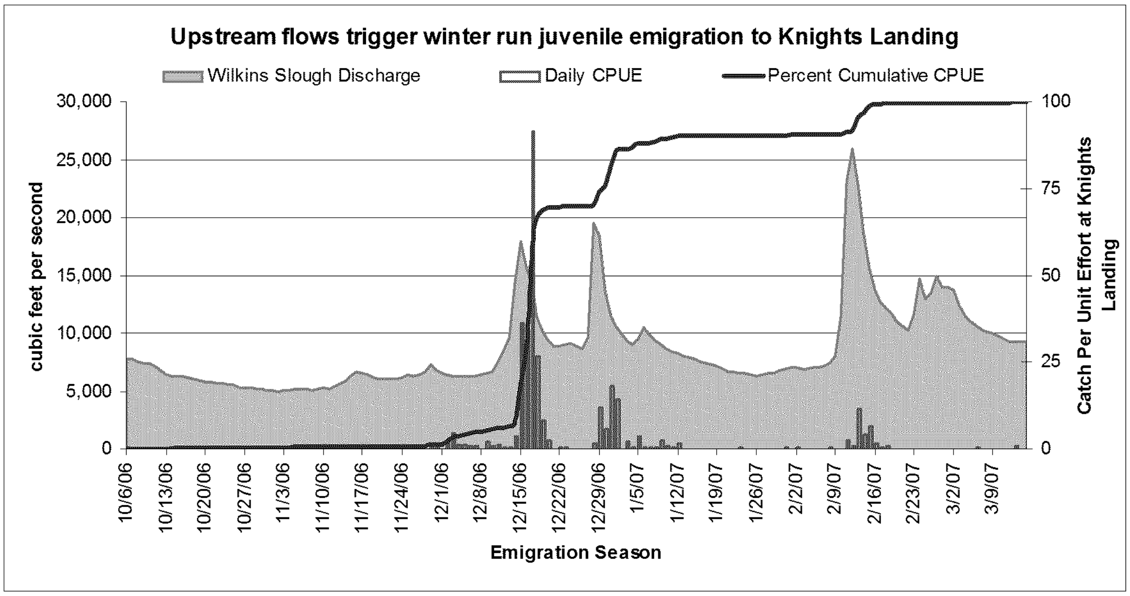


**Figure 1. Catch of juvenile winter-run Chinook salmon in the Knight's Landing rotary screw trap (blue bars) versus Wilkins Slough discharge into the Sacramento River (gray fill). The cumulative salmon catch is shown as a red line. The data are a single emigration-season example from 2006-2007. CPUE = Catch per unit effort.**

**Table 5. Various proposed cumulative durations (number of days) that Freeport flow should be required to exceed 20,000 cfs before moving to progressively less restrictive water diversion operations. Levels I-III represent step increases in allowable**

**proportion of Sacramento River flow available for export.**

| *Model scenario* | *Days needed for initial pulse protection* | *Days needed to move from Level I to Level II Post-Pulse Operations* | *Days needed to move from Level II to Level III Post-Pulse Operations* |
|---|---|---|---|
| Steering Committee Range B and EIR/S "Enhanced Aquatic" Alternative 4 | 10 | 20 | 45 |
| Steering Committee Preliminary Proposal, Scenario 6 | 10 | 15 | 30 |
| Steering Committee Range A | 0 | 10 | 20 |

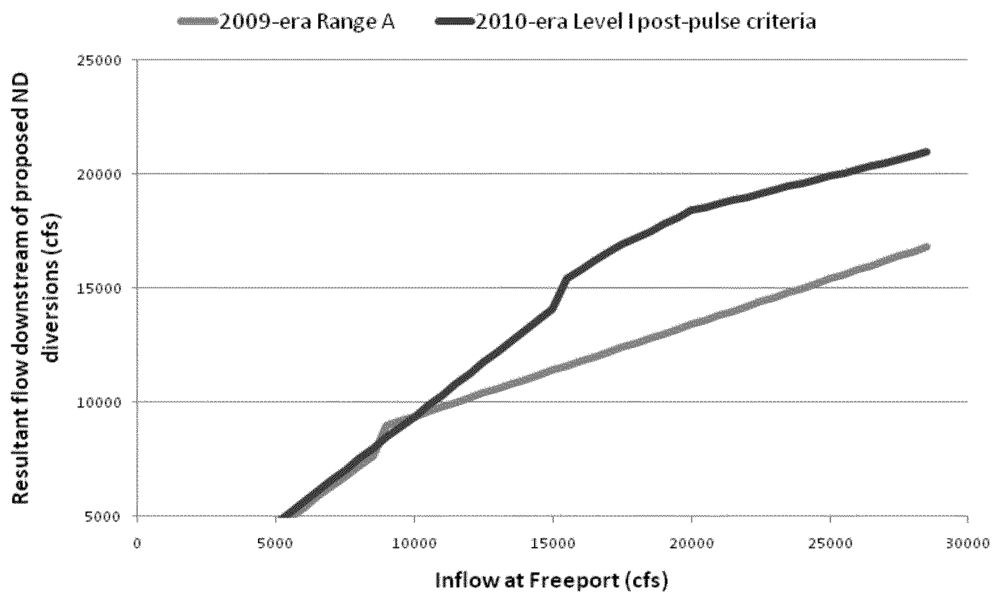


**Figure 2. Comparison of Sacramento River flows that would occur downstream of proposed North Delta water diversions during March under the two operational scenarios listed in the legend. Only data for Sacramento inflows up to 30,000 cfs at Freeport are shown. At higher flows, the lines begin to converge.**

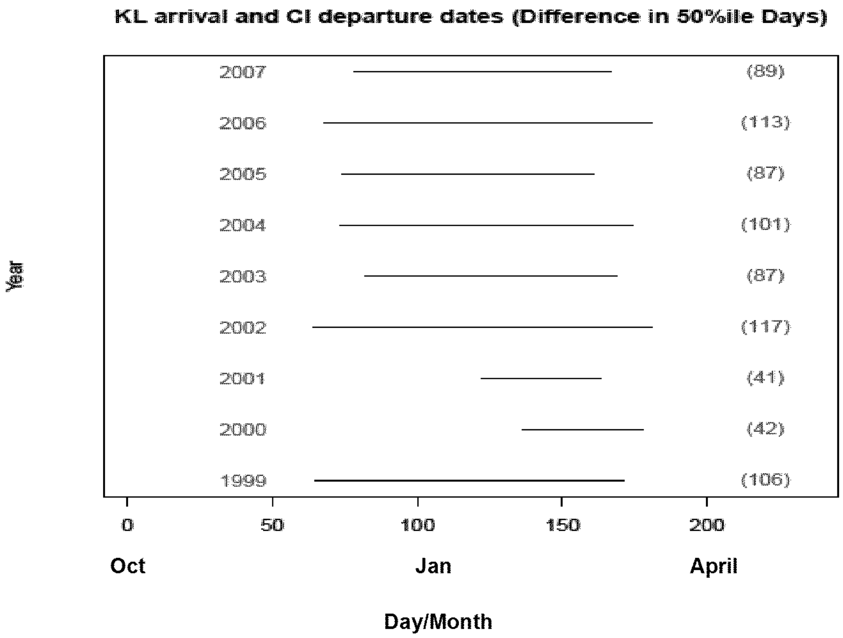


**Figure 3. Estimated juvenile winter-run Chinook salmon residence times in the Delta, 1999-2007. Residence time is defined as the number of days that transpired between when 50% of the annual winter-run catch total had passed Knight's Landing to when 50% of the annual catch total had passed Chipps Island. Chipps Island is the approximate boundary between the legally-defined Delta and Suisun Bay. Year is shown in red font. The black lines show these durations. The blue numbers in parentheses are the residence time estimates in days. KL = Knight's Landing; CI = Chipps Island.**

***Rationale for Managed Fremont Weir Flows***: A range of Fremont Weir flows are recommended which would increase the frequency and duration of Yolo Bypass inundation and to facilitate passage of adult salmonids and sturgeon. Management of Fremont Weir flows is expected to intermittently enhance juvenile salmon growth and survival (Sommer et al. 2001; 2005), improve splittail recruitment (Feyrer et al. 2006b), and provide a seasonal infusion of prey to fishes inhabiting the Cache Slough region, particularly during floodplain drainage (Sommer et al. 2004; Lehman et al. 2008a). We expect that juvenile fall-run and winter-run Chinook salmon, larval delta smelt, and larval splittail will be most likely to benefit from invertebrate production coming from Yolo Bypass drainage.

The adaptive range for restricted notch flows (as opposed to natural overtopping) at Fremont Weir may be informed by the initial performance measure required by NMFS (2009; Action I.6.1). This action requires 17,000-20,000 acres of floodplain inundation in the Lower Sacramento River watershed, most of which is assumed will occur within the Yolo Bypass.

Recent two-dimensional modeling completed for the February 2011 BDCP Effects Analysis simulated the inundation acreage resulting from eight existing (westside tributary flows only, Run ID 1E-8E) and seven proposed (westside tributary flows plus restricted notch flows, Run ID 2P-8P) scenarios. These results indicate that the contribution of westside tributary flows to the total inundation area is typically greater than the increase due to the notched weir flows (Table 6). Since similar 2-D modeling was not completed to show inundation exclusively due to restricted notched weir flows, we could not determine what lower flow is appropriate for an adaptive range of notched weir operations that will sufficiently inundate the Yolo Bypass when the westside tributary contributions are less than what was modeled. Additionally, the modeling did not provide information on the frequency or duration of inundation, or the rate of flood recedence. These time-related factors would influence the potential for beneficial ecological effects of inundation. The inundated acreage of Yolo Bypass can change by more than 100% per day (Sommer et al. 2004). We recommend that future Yolo Bypass and other floodplain inundation assessments be reported in units of acre-days (inundated acreage times the number of days that inundated acreage is achieved).

**Table 6. Summary of Yolo Bypass inundation results. Data source: February 2011 Effects Analysis (BDCP 2011).**

| Existing Run ID | Total Flow (cfs) | Inundation Area (acres) | Proposed Run ID | Notch Flow (cfs) | Total Flow (cfs) | Inundation Area (acres) | Inundation Area Increase (acres) |
|---|---|---|---|---|---|---|---|
| 1E | 1125 | 6377 | - - - | 0 | - - - | - - - | - - - |
| 2E | 2170 | 8035 | 2P | 1000 | 3170 | 12671 | 4637 |
| 3E | 2647 | 9733 | 3P | 2000 | 4647 | 17082 | 7349 |
| 4E | 3073 | 11110 | 4P | 3000 | 6073 | 19310 | 8200 |
| 5E | 2976 | 10863 | 5P | 4000 | 6976 | 20416 | 9553 |
| 6E | 4343 | 15711 | 6P | 5000 | 9343 | 23027 | 7316 |
| 7E | 4037 | 15621 | 7P | 6000 | 10037 | 23821 | 8199 |
| 8E | 6289 | 19244 | 8P | 6000 | 12289 | 25136 | 5893 |

The 2011 BDCP Effects Analysis includes the results of previously completed one-dimensional HEC-RAS modeling of the inundation area due to notched weir flows (excluding westside tributaries). These results are not directly comparable to the 2-D modeling results described above because of the exclusion of westside tributaries, inclusion of Liberty Island's wetted tidal marsh acreages, differences in boundary conditions (steady-state vs. tidal) and bathymetric data resolution. The HEC-RAS results provide inundation areas for given flow events, but they do not provide the data lacking from the more recent 2-D modeling effort. The incomplete results of these two modeling efforts support the recommendation for additional two-dimensional modeling of restricted notched weir flows to determine the range of flows that is required to meet the performance measure specified by NMFS (2009).

The Team proposes that the adaptive range should also include variation in the flows through Fremont Weir's 11.5 foot elevation gate to support passage of adult fish from the Yolo Bypass back into the Sacramento River above Fremont Weir. The Team suggests a range from the proposed value of 100 cfs up to 1,000 cfs, the maximum capacity of the Tule Canal/Toe Drain in the northern extent of the Bypass. Flows higher than 1,000 cfs would risk inundating acreage outside of this channel and would thus be more than passage flows. A wide range is recommended at this time because little is known about the specific design of the proposed fish passage structure at Fremont Weir, the differences in passage behavior of multiple species, and the adequacy of 100 cfs to meet currently unidentified performance measures for fish passage at the Fremont Weir.

***Rio Vista Flows***: D-1641 sets a minimum flow of 3,000 cfs to 4,500 cfs at Rio Vista from September through December. Due to a lack of data specifically linking flow at Rio Vista to fish responses, we do not discuss flow needs for BDCP target fishes in terms of this parameter. Instead, see the sections on Old and Middle River flows and Delta outflow.

***Delta Cross Channel***: The primary Fish Agency goal of Delta Cross Channel gate operations is to reduce the fraction of juvenile salmonids emigrating into the interior Delta, where their survival can be impaired (Brandes and McLain 2001; Newman and Rice 2002; Newman 2008; Newman and Brandes 2010).

Another goal is the maintenance of State-mandated water quality standards in the interior Delta. To date, all proposed operations scenarios have included Delta Cross Channel gate operations that meet NMFS' (2009) requirements. We have not found any suggested alternatives to the operations shown in Table 7. However, for the purposes of an adaptive range, we propose that the DCC operations during October-November could vary from 0-100%. This would capture a wide range of potential futures for balancing among water quality needs in the Delta, maximizing survival of Sacramento basin salmonids if emigration timing shifts with climate change, and minimizing the straying risk of adult Mokelumne River salmonids.

**Table 7. The Steering Committee Preliminary Proposal Delta Cross Channel operations schedule.**

| *Month* | *% of time DCC proposed to be open in PP* | *Adaptive Range for % of time DCC open* |
|---|---|---|
| Jan | 0% | 0% |
| Feb | 0% | 0% |
| Mar | 0% | 0% |
| Apr | 0% | 0% |
| May | 0% | 0% |
| Jun | 0% | 0% |
| Jul | 100% | 100% |
| Aug | 100% | 100% |
| Sep | 100% | 100% |
| Oct | 48%[a] | 0-100% |
| Nov | 50%[a] | 0-100% |
| Dec | 0% | 0% |

[a]Assumed to be shut for 15 days each month if needed to protect early migrating juvenile salmon from this pathway into the central Delta.



***Rationale for Old and Middle River Flow Criteria***: The goals of the Old and Middle River flow criteria (OMR) are to contribute to lower fish entrainment in the southern Delta and to increase native fish survival in the interior Delta by increasing the recurrence frequency of net downstream flows in the South Delta. There is no substantive scientific disagreement that reverse flows influence fish entrainment or that some reverse flow management is desirable. However, there is disagreement about the amount of reverse flow management that is needed, and its expected influence on fish populations (e.g., Kimmerer 2008; Brown et al. 2009; Kimmerer 2011; Miller 2011; Maunder and Deriso 2011).

The Delta is a tidal system and peak tidal flows are almost always much greater than river inflows (Kimmerer 2004). Nonetheless, river inflows and export flows strongly influence Delta hydrodynamics (Kimmerer and Nobriga 2008) and by extension, the transport of water quality constituents (Monsen et al. 2007), planktonic production (Jassby et al. 2002), and fishes (Kimmerer 2008; Grimaldo et al. 2009). The net (tidally-filtered) OMR flows measured on either side of Bacon Island are one indicator of the extent of hydrodynamic influence exerted on the southern Delta by the Banks and Jones pumping plants (Arthur et al. 1996). The highest BDCP target fish salvage rates (an indicator of entrainment rates) observed at the CVP/SWP water export facilities have often been associated with net negative OMR flows, indicating a mechanistic linkage between South Delta hydrodynamics and fish entrainment

(Kimmerer 2008; Grimaldo et al. 2009). This linkage is intuitive based on particle tracking models of Delta hydrodynamics (Kimmerer and Nobriga 2008; Kimmerer 2008; 2011).

The hydrodynamic linkage between OMR and particle entrainment risk is easily demonstrable from existing modeling data (Figure 4). Based on evidence from DWR's DSM-2 Particle Tracking Model, OMR flows ≥ -2,000 cfs reflect a Water Project influence that is largely restricted to Old and Middle rivers themselves. Thus, particle entrainment risk from the mainstem San Joaquin River is low at this flow. As OMR becomes increasingly negative, particle entrainment risk increases. OMR flows less than (more negative) approximately -5,000 cfs reflect a hydrodynamic influence extending into the mainstem of the San Joaquin River and thus a higher likelihood of particle entrainment.

While particle tracking models are informative for particle fate, *fish* entrainment depends on numerous context-dependent interactions of OMR with other factors like fish distribution and abundance (Sommer et al. 1997; Grimaldo et al. 2009), fish size (Kimmerer 2008), water temperature and turbidity in the South Delta (Kimmerer 2008; Grimaldo et al. 2009; Deriso 2011), fish points of entry into the Delta (sensu Newman 2002; 2008), fish behavior (Coutant and Whitney 2002), and the balance between travel time, cumulative loss to predators, and pumping-induced movement velocity [i.e., whether the export pumping is moving fish toward the fish facilities faster than predators are removing them (Anderson et al. 2005; Odeh 2002)].

***Evolution of Technical Expert Thinking About How the Old and Middle River Flow Criteria Need to Work to Protect the BDCP Target Fishes***: OMR management has been a key regulatory tool in recent years (USFWS 2008; CDFG 2009; NMFS 2009). However, it has been contentious because there is no exact OMR at which fish entrainment will or will not be observed at the South Delta Fish Facilities (Kimmerer 2008; Deriso 2011; USFWS 2011). As a result of the biological opinions from USFWS (2008) and NMFS (2009), OMR limits are set typically on a weekly basis based on a combination of expert opinion and management directive using real-time data. We expect this general strategy will be a component of BDCP implementation, but there is a need to find ways to approximate expected management responses to changing conditions in CALSIM-II, which is limited to modeling Project operations on a monthly time-step. As described below, proposals have ranged from unvarying monthly OMR limits to flexible OMR limits that vary depending on water-year type or modeled Delta inflows. We note that the inflow-based rules are the most flexible in terms of responsiveness to modeled hydrology. Thus, they are best suited to balancing fish protection and water supply reliability in CALSIM-II.

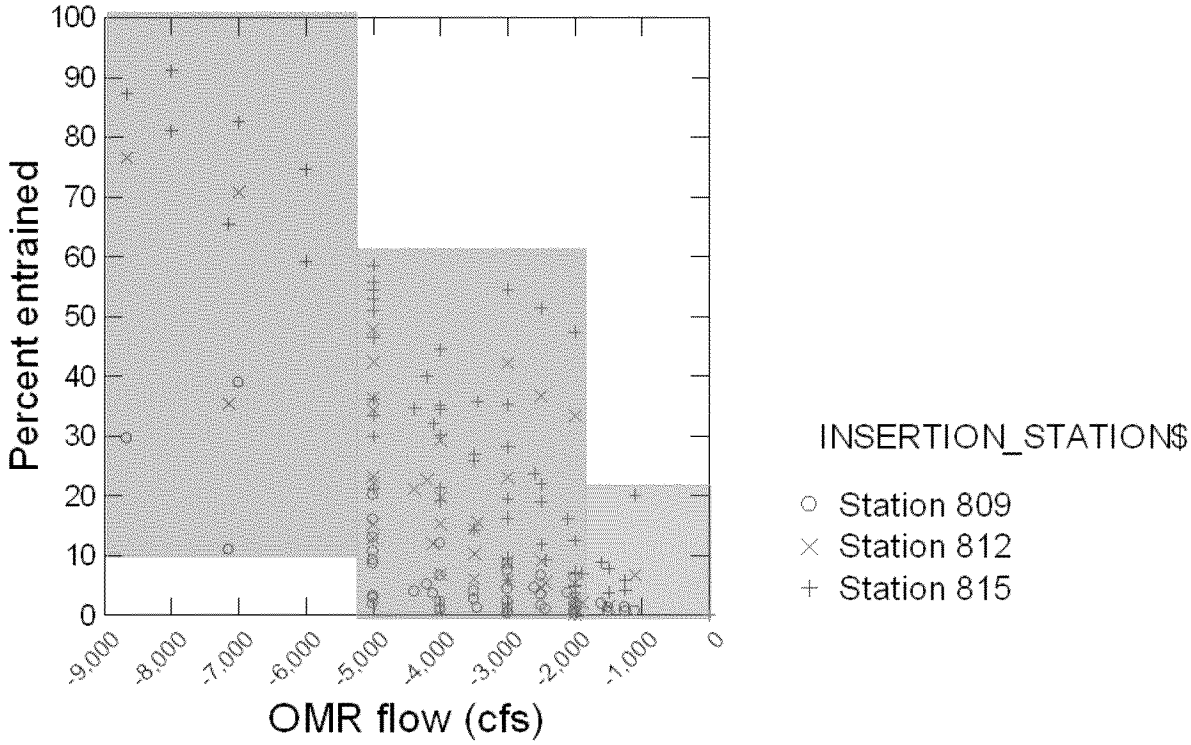


**Figure 4. Scatterplot of net Old and Middle River flow (OMR) versus particle entrainment at the Banks and Jones Pumping Plants from several release sites on the San Joaquin River (source: USFWS 2011). Stations: 809 – Jersey Point; 812 – Fisherman's Cut/SJ River; 815 – Mouth of Old River. The colored boxes envelope the OMR ranges discussed in this document.**



There have been a wide range of OMR flow proposals within BDCP, and others have been proposed during the concurrent OCAP litigation. The simplest waypoints have proposed a single OMR limit that must always be met. For instance, the *Steering Committee Range A* operations proposal had a -6000 cfs limit during December-June and no limit during July-November when target fishes were less likely to be entrained based on historical salvage data. Early draft versions of the *Steering Committee's Preliminary Proposal* operations set OMR limits that varied among months by water-year type (Table 8).

More complex OMR rules – including those used in the OCAP Biological Opinions (USFWS 2008; NMFS 2009) – have been based on dynamic operating rules that vary OMR within a range in response to some of the previously-noted context-dependent interactions between OMR and fish entrainment. For instance, the CALSIM-II modeling for the *Steering Committee's February 2010 Preliminary Proposal* varied the OMR criteria from -1250 cfs to -5000 cfs based on modeled Sacramento River flows at Freeport to simulate compliance with USFWS (2008) and NMFS (2009) criteria (CH2M-Hill 2009a,b).

**Table 8. Steering Committee draft OMR criteria (6/30/2009) based on water-year type classifications: Wet = wet, AN = above-normal, BN = below-normal, D = dry, and C = critically dry. NL = no OMR flow limit proposed.**

| ***Month*** | ***Wet*** | ***AN*** | ***BN*** | ***D*** | ***C*** | ***Species and life-stages salvaged[1]*** |
|---|---|---|---|---|---|---|
| Oct | NL | NL | NL | NL | NL | Sacramento River Chinook salmon smolts, juvenile sturgeon |
| Nov | NL | NL | NL | NL | NL | Sacramento River Chinook salmon smolts, juvenile sturgeon |
| Dec | -6839 | -6839 | -6258 | -6258 | -6065 | Sacramento River Chinook salmon smolts, adult longfin smelt, juvenile sturgeon |
| Jan | -4000 | -4000 | -4000 | -5000 | -5000 | Sacramento River Chinook salmon smolts, fall-run Chinook salmon fry, adult longfin smelt, larval longfin smelt (seldom observed), adult delta smelt |
| Feb | -5000 | -4000 | -4000 | -3500 | -3000 | All salmonid smolts, fall-run Chinook salmon fry; larval longfin smelt (seldom observed), adult delta smelt |
| Mar | -5000 | -4000 | -4000 | -3500 | -2000 | All salmonid smolts, fall-run Chinook salmon fry; larval longfin smelt (seldom observed), adult delta smelt |
| Apr | -5000 | -4000 | -4000 | -3500 | -2000 | All salmonid smolts, fall-run Chinook salmon fry; larval-juvenile longfin smelt, larval delta smelt (seldom observed) |
| May | -5000 | -4000 | -4000 | -3500 | -2000 | Fall-run and spring-run Chinook salmon smolts, larval-juvenile delta smelt, juvenile longfin smelt, juvenile splittail |
| Jun | -5000 | -5000 | -5000 | -5000 | -2000 | Fall-run and spring-run Chinook salmon smolts, juvenile delta smelt, juvenile splittail |
| Jul | NL | NL | NL | NL | NL | Juvenile splittail, juvenile sturgeon |
| Aug | NL | NL | NL | NL | NL | Juvenile sturgeon |
| Sep | NL | NL | NL | NL | NL | Juvenile sturgeon |

[1]CDFG Salvage Database. ftp://ftp.delta.dfg.ca.gov/salvage/

The CALSIM-II modeling outputs for two of the BDCP scenarios were also used to guide the development of OMR criteria linked to San Joaquin River inflow at Vernalis. Like the NDDB flow criteria, these inflow-based OMR criteria can be easily modeled using CALSIM-II because they are informed by it and do not rely on assumptions about less predictable variables such as turbidity. They should also be easily implemented because river flow at Vernalis is known in real-time, whereas categorical variables such as water-year type are not. Two OMR waypoints based on Vernalis inflow during April-June are shown in Figure 5.

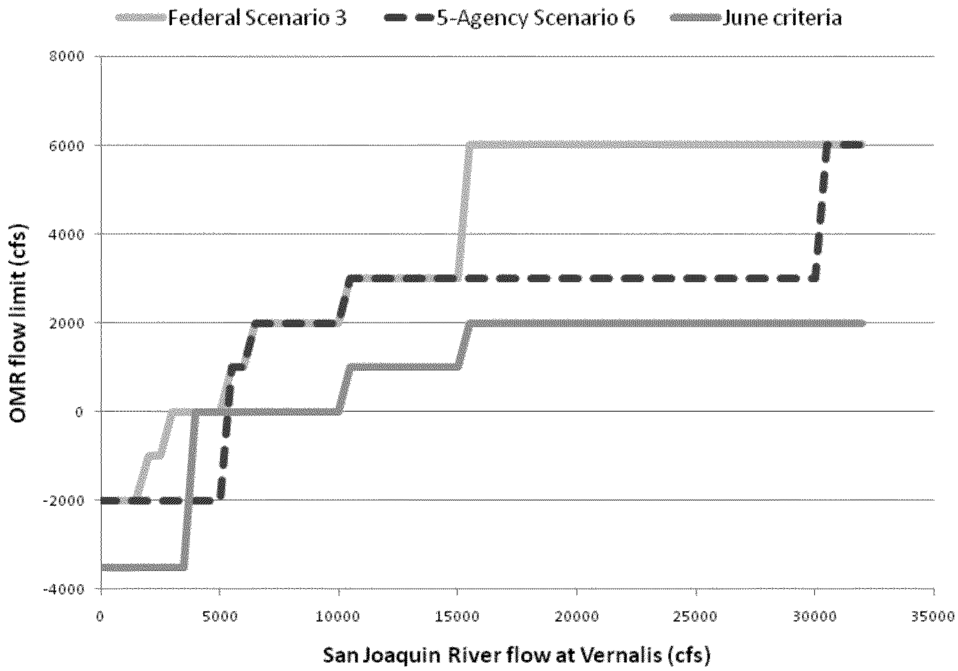


**Figure 5. Examples of April-June OMR flow criteria linked to San Joaquin River inflow at Vernalis. Scenarios 3 and 6 differ during April and May but are the same for the month of June as identified in the figure.**



*<u>Why is there high scientific uncertainty about how to best use dual conveyance during the summer?</u>*

The summer months (July-September) may be the period of greatest planning uncertainty regarding the environmental effects of future water exports using dual conveyance. By extension, this includes OMR management. The reason is that, except for sturgeon, which are not usually salvaged in high numbers, BDCP target fish entrainment reaches its annual lows during the summer (USFWS 2008; NMFS 2009). Thus, the summer months challenge current scientific conceptual models about whether the primary environmental impact associated with water exports from the Delta is seasonal (i.e., related to entrainment of fishes) or chronic (i.e., related to water withdrawal itself through effects on water quality and the food web). This leads to two possible endpoints that will need to be the subject of future scientific evaluation and management adaptation. These endpoints are discussed below.

***The Potential Pros and Cons of Favoring Either North or South Delta Diversions During the Summer***:
Dual conveyance could allow most or all summertime (July-September) water diversions to be fulfilled by the proposed Sacramento River North Delta facility. Using the North Delta as the source of all diversions would maximize summertime OMR flow and the contribution of San Joaquin River water to the estuary. This could be desirable since phytoplankton density in the San Joaquin River is higher than in the Sacramento River (Jassby 2008), and the increase could stimulate estuarine zooplankton

production needed by some BDCP target fishes. This potential food web benefit is labeled '*Pseudodiaptomus* flux' in Figure 6 because *Pseudodiaptomus* is one of the key zooplankton prey species that blooms in the Delta and has to be transported into the low-salinity zone to be available to fishes like delta smelt. However, the San Joaquin River also carries a comparatively high selenium load and increasing its contribution to Delta outflow might exacerbate selenium bioaccumulation in estuarine fishes and birds, which already sustain selenium body burdens near thresholds known to impair reproduction (Linville et al. 2002, Stewart et al. 2004).

Given the current NDDB flow criterion, Sacramento River flows downstream of the North Delta diversions could be less than 5,000 cfs for months at a time. Currently, the North and West Delta are the best-available resident native fish habitats left in the Project Area upstream of Suisun Marsh (Nobriga et al. 2005; Brown and Michniuk 2007). If the elevated Sacramento River inflows that support current South Delta water exports are important to these fishes during summer and fall, then reduction of Sacramento River flow by North Delta diversions could lead to further habitat change and dominance by nonnative species.

The CALSIM-II modeling done to support BDCP also indicates that San Joaquin River inflows during the summer months would almost always be less than 5,000 cfs, and frequently less than 3,000 cfs (Figure 7). The low river inflows will be reduced further by irrigation diversions during the summer. This will likely lead to higher hydraulic residence times and lower South Delta circulation, which may exacerbate undesirable water quality problems like oxygen depletion (Lehman et al. 2004) and *Microcystis aeruginosa* blooms (Lehman et al. 2008b).

The alternative is to favor or exclusively use South Delta diversions during July-September. Current water management strategies do not result in desirable ecological conditions for water quality or BDCP target fishes during the summer (Lehman et al. 2008b; 2010; Moyle and Bennett 2008; Figure 7). However, it is possible that when entrainment risk for target species is low, the infusion of significant amounts of Sacramento River water into the South Delta will create ecological conditions that are a best-case scenario with respect to flow management, and that ecological improvements during the summer months will need to rely heavily on management of 'other stressors'.



Thus, we recommend the adaptive range for July-September operations include possibilities from 100% use of the North Delta diversions to 100% use of South Delta diversions. This range will allow for full future experimentation to achieve the best balance of fish and water quality needs.

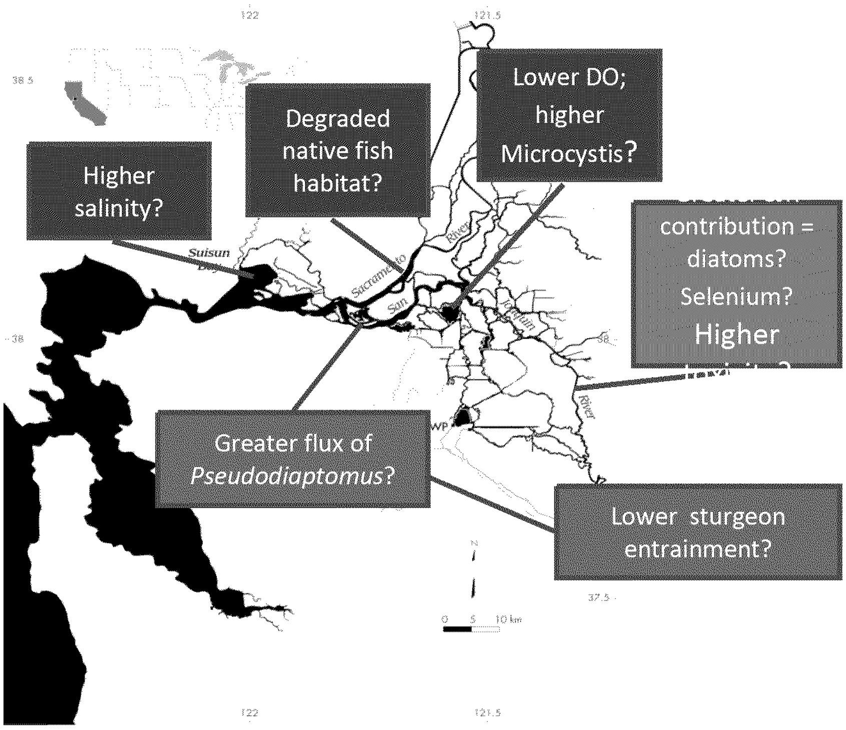


**Figure 6. Operations in summer months have a natural range of preferring 100% of diversions from North Delta to 100% of diversions from South Delta. Actual distribution could vary based on concerns over water quality, DO, zooplankton production, spread of exotic species, and entrainment. Taking water just from the north could help improve food production and reduce entrainment.**



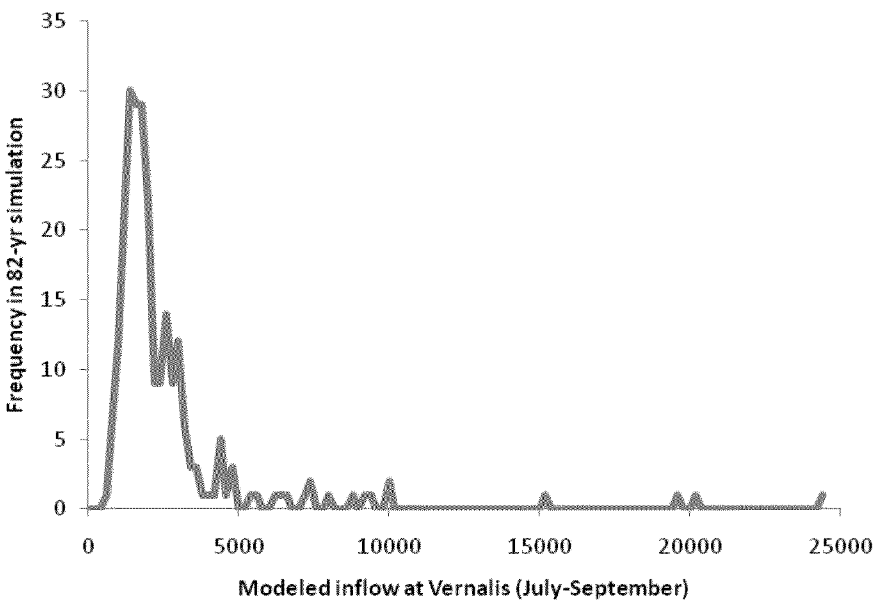


**Figure 7. Frequency distribution of Vernalis inflows modeled for the BDCP Feb 2010 Preliminary Proposal, July-September combined.**

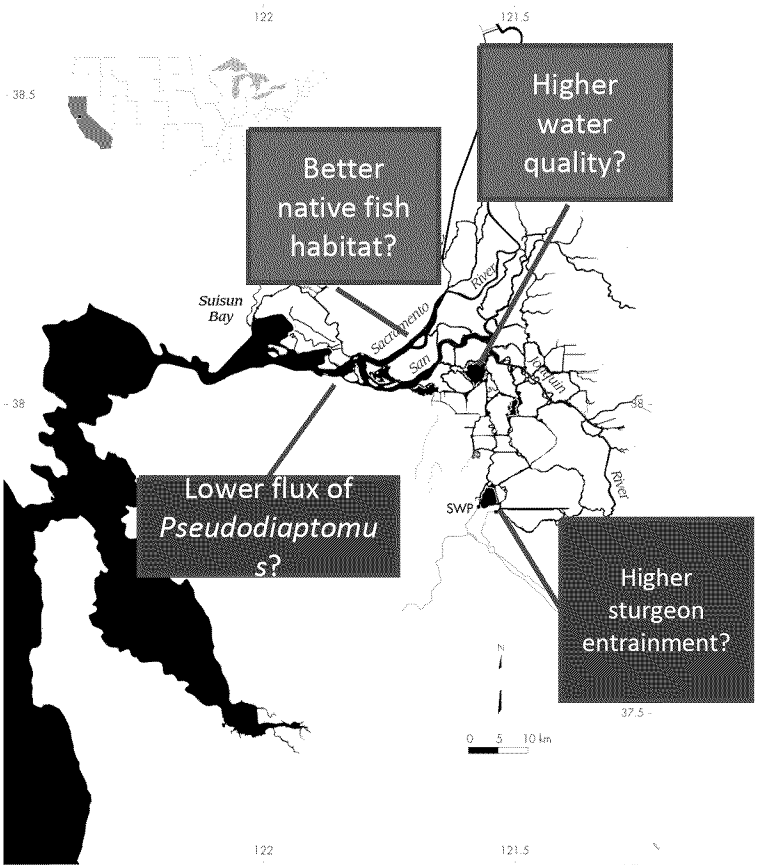


**Figure 8. Taking water just from the south could help habitat and water quality in the north, and potentially increase sturgeon entrainment.**

*Why has the Team recommended re-evaluating options for protecting San Joaquin River Basin salmonids?*

***D-1641 Fall Flow Pulse***: This 14-day pulse flow is part of SWRCB Decision 1641, not a BDCP Conservation Measure. The goal of the pulse flow is to provide a detectable attraction flow for San Joaquin River Chinook salmon and to increase water quality in the river. The Team explored ways to maximize the efficacy of this State-mandated flow pulse using combinations of OMR flows, a physical barrier at the head of Old River, and temporary cessation of South Delta exports. Operation of the physical barrier at the head of Old River assumes the current operation of agricultural barriers that open and close appropriately to protect irrigation water levels and water quality in the South Delta.

***Rationale for an Operable Barrier at the Head of Old River***: The goal of an operable Head of Old River barrier (HORB) is to increase the survival of juvenile salmonids emigrating from San Joaquin River tributaries during spring and to increase the homing of adult Chinook salmon during the fall. The HORB may also increase the survival of juvenile splittail produced in the San Joaquin River, but this hypothesis has not be tested. The empirical support for improved Chinook salmon survival was summarized by Newman (2008). Several factors would influence HORB gate operations and therefore the full range of 0% to 100% open is included in the waypoints. The non-physical (bubble) barrier is analogous to 100% open, and is therefore included among the waypoints. Some of the factors that would influence gate operations include: flood flow management, water quality (salinity, DO), water temperature for outmigration, flow stage for in-Delta irrigation diversions, interactions between fish species and life stages, fish migration behavior and timing (diurnal, tidal), and inundation of restored habitats in the South Delta.

***South Delta Export Rates***: It is possible that dual conveyance will provide opportunities to temporarily cease exports from the South Delta to achieve fishery benefits. The 'Enhanced Aquatic Alternative 4' proposed as part of the NEPA analysis of the BDCP is the only planning scenario we found that recommended extended periods of zero exports from the South Delta and very positive OMR limits that would equate to zero South Delta export much of the time at the San Joaquin River inflows that were modeled. The goal was to maximize the theoretical extent that dual conveyance could be used to improve South Delta flows during times of year that the BDCP target species might spawn, rear, or migrate through, the South Delta (October-June). The proposed cessation of South Delta exports during spring in Enhanced Aquatic Alternative 4 was proposed to provide maximum protection from entrainment for San Joaquin River basin salmonids. Note that a HORB was not part of the Alternative 4 proposal. Therefore, OMR limits would have less meaning for these fishes because many of them migrate through Old River right past the South Delta Facilities. The pumping rates and inflows to Jones Pumping Plant and Clifton Court Forebay when fish are migrating past these facilities are much more relevant to their entrainment risk than net river flows several miles seaward.

Some modeled scenarios included a period of zero South Delta exports, but these are much more modest than the EIR/S alternative described above. These scenarios recommend a 14-day period with no South Delta exports during October to coincide with the D-1641 autumn flow pulse intended to act as an attraction flow pulse for San Joaquin River fall-run Chinook salmon (Mesick 2001). The objective is to ensure that some of the flow required at Vernalis would travel through the Delta without being exported in order to maximize the continuity of olfactory cues distributed between Vernalis and points further downstream along the San Joaquin River.



***Rationale for Delta Outflow and X2 Standards***: There is strong scientific evidence that climatic-scale flow variation (i.e., the interannual variation in river flows moving through the watershed and into and through the estuary) influences the survival and abundance of almost all of the BDCP target fishes (Kjelson et al. 1982; Stevens and Miller 1983; Kjelson and Brandes 1989; Kohlhorst et al. 1991; Jassby et al. 1995; Sommer et al. 1997; Kimmerer 2002a,b; Newman 2003; Fish 2010; Mac Nally et al. 2010; Perry et al. 2010; Thomson et al. 2010). Thus, the goal of Delta outflow standards is to contribute to increased estuarine habitat suitability that supports the successful migration and production of multiple species and their supporting food web. Note that Delta outflow standards are currently defined in terms of flow rates, salinity at compliance points, export to inflow ratios, or the average physical location of the 2 psu salinity isohaline in the estuary (SWRCB 1995).

At higher Delta outflows, more habitat[2] becomes available for estuarine rearing due to floodplain inundation and changes in the extent and location of the low-salinity zone. For example, in years with high outflow, fall-run Chinook salmon fry are found rearing all the way down into San Francisco Bay, probably due to lower salinity in the bays (Kjelson et al. 1982). This is an important strategy in maintaining life-history diversity in a species whose current low escapements are dominated by hatchery fish. Reductions in Delta outflow during wetter years may also negatively impact sturgeon (Fish 2010; USFWS 1995). CDFG (1992) has linked the percent of Delta inflow diverted (Delta E/I) in the spring and summer months to poor sturgeon year class indices.

[2] DWR has not agreed that current science supports this conclusion.

The managed use of Delta outflow as a component of estuarine habitat maintenance and restoration is contentious because it can require substantial additions of stored water supply and foregone water exports. This not only reduces water supply for human consumptive uses, but can also affect the coldwater pools in Project reservoirs that are used to maintain suitable habitat conditions for salmonid fishes during the summer and fall. This tension among storage, consumptive use of freshwater, and Delta outflow is heightened by the inability to quantitatively parse the numerous positive effects of Delta outflow for different species and life stages (Kimmerer 2002a). In other words, the positive effects of tributary flows, floodplain inundation, Delta inflows, and Delta outflows are often confounded such that it is not clear how much of the cumulative benefit of providing river flows to the estuary has been achieved for species at the time the water reaches a given point (e.g., Knight's Landing, Sacramento, Rio Vista, Chipps Island). We have summarized the state of science regarding this cascade of potential flow benefits to all 11 BDCP target fishes in Table 9. Resolving these flow-related mechanism questions should be a high priority for BDCP-related monitoring, research, and adaptive management efforts.

**Table 9. Matrix of use of the Sacramento River corridor by the BDCP target fish species. Note that river flows have to pass the specified region to influence the life stage(s) listed for that region. The life stages shown to have vital rates or survival strongly influenced by river flows *in a given reach* are in bold text with references as footnotes.**

| River reach | Pacific lamprey | River lamprey | White sturgeon | Green sturgeon | Fall/late-fall Chinook salmon | Spring-run Chinook salmon | Winter-run Chinook salmon | Steelhead | Longfin smelt | Delta smelt | Splittail |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Keswick Dam to the confluence of the Feather River | Spawning and larval rearing habitat; adult and larval-juvenile migration corridor | Spawning and larval rearing habitat; adult and larval-juvenile migration corridor | **Spawning and larval rearing habitat**[a]; adult and larval-juvenile migration corridor | Spawning and larval rearing habitat; adult and larval-juvenile migration corridor | Spawning and fry rearing habitat; adult and juvenile migration corridor | Spawning and fry rearing habitat; adult and juvenile migration corridor | **Spawning and fry rearing habitat; adult and juvenile migration corridor**[b] | Spawning and fry rearing habitat; adult and juvenile migration corridor | NA | NA | Spawning and larval rearing habitat (Sutter Bypass etc.) |
| Confluence of the Feather River to the confluence of the American River (including the seasonally flooded part of Yolo Bypass) | Possible larval rearing habitat; adult and juvenile migration corridor | Possible larval rearing habitat; adult and juvenile migration corridor | Possible larval rearing habitat; adult and juvenile migration corridor | Possible larval rearing habitat; adult and juvenile migration corridor | **Juvenile rearing habitat**[c]; adult and **juvenile migration corridor**[c] | Juvenile rearing habitat; adult and juvenile migration corridor; not known to use Yolo Bypass to any substantive extent | **Juvenile rearing habitat**[d]; adult and juvenile migration corridor | Juvenile rearing habitat; adult and juvenile migration corridor; not known to use Yolo Bypass to any substantive extent | NA | NA | **Spawning and larval rearing habitat in years of high river flow (Yolo Bypass)**[e]; adult and juvenile migration corridor |
| Confluence of the American River to Rio Vista (including the Cache Slough region) | Possible larval rearing habitat; adult and juvenile migration corridor | Possible larval rearing habitat; adult and juvenile migration corridor | Possible larval rearing habitat; juvenile rearing habitat; adult and juvenile migration corridor | Possible larval rearing habitat; adult and juvenile migration corridor | **Juvenile rearing habitat**[f]; adult and **juvenile migration corridor**[f] | **Juvenile rearing habitat**[f]; adult and **juvenile migration corridor**[f] | **Juvenile rearing habitat**[f]; adult and **juvenile migration corridor**[f] | Possible juvenile rearing habitat; adult and juvenile migration corridor | Spawning and larval rearing habitat in years of low river flow | Spawning habitat; rearing habitat for all life stages (Cache Slough region) | Larval-juvenile rearing habitat; adult and juvenile migration corridor |
| Rio Vista to Chipps Island | Adult and juvenile migration corridor | Adult and juvenile migration corridor | Juvenile rearing habitat; adult and juvenile | Possible juvenile rearing habitat; adult and | Juvenile rearing habitat; adult and juvenile | Juvenile rearing habitat; adult and juvenile | Juvenile rearing habitat; adult and juvenile | Possible juvenile rearing habitat; adult and juvenile | Spawning and larval rearing habitat; adult and | Spawning habitat; **rearing habitat for all life** | Larval-juvenile rearing habitat; migration |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | migration corridor | juvenile migration corridor | migration corridor | migration corridor | migration corridor | migration corridor | larval migration corridor | **stages**[g] | corridor for all life stages |
| Chipps Island to the confluence of the Napa River (including Suisun Marsh) | Adult and juvenile migration corridor | Adult and juvenile migration corridor | Juvenile rearing habitat; adult and juvenile migration corridor | Juvenile rearing habitat; adult and juvenile migration corridor | Juvenile rearing habitat (Suisun Marsh); adult and juvenile migration corridor | Adult and juvenile migration corridor | Adult and juvenile migration corridor | Adult and juvenile migration corridor | **Spawning and larval-juvenile rearing habitat**[h]**; adult and larval-juvenile migration corridor**[i] | **Spawning habitat; rearing habitat for all life stages**[j] | **Spawning habitat**[k]; rearing habitat for all life stages |
| Confluence of the Napa River to the Golden Gate | Adult and juvenile migration corridor | Adult and juvenile migration corridor | Juvenile rearing habitat; adult and juvenile migration corridor | Juvenile rearing habitat; adult and juvenile migration corridor | Adult and juvenile migration corridor | Adult and juvenile migration corridor | Adult and juvenile migration corridor | Adult and juvenile migration corridor | Juvenile-adult rearing habitat; adult migration corridor | Adult and **larval migration corridor in years of high river flow**[l] | Possible migration corridor in years of high river flow |

[a]Moyle (2002)
[b](Moyle (2009)
[c]Sommer et al. 2001; 2005
[d]NMFS unpublished data
[e]Sommer et al. 1997; 2002
[f]Kjelson and Brandes 1989; Newman 2003; Perry 2010
[g]Dege and Brown 2004; Feyrer et al. 2007; 2011
[h]Hobbs et al. 2006; 2010
[i]DFG 2009
[j]Sweetnam 1999; Dege and Brown 2004; Hobbs et al. 2006; 2007; Feyrer et al. 2007; 2010; Nobriga et al. 2008
[k]Meng and Matern 2001
[l]Hobbs et al. 2007

Like OMR flow management, the management of Delta outflow highlights differing scientific conceptual models about whether the primary environmental impact associated with water exports is seasonal (i.e., related to entrainment of fishes) or chronic (i.e., related to both entrainment and water withdrawal itself). For most if not all of the BDCP target fishes, Delta outflow and entrainment risk are intimately linked. Either low outflow results in landward shifts in rearing habitat, thereby increasing the proportion of a population that is potentially vulnerable to entrainment, or high outflow is associated with high species abundance, which is reflected in fish salvage (Sommer et al. 1997). The relationships between Delta outflow and abundance of a number of estuarine species are well known and were a major part of the rationale for the SWRCB (1995) criteria. It is also understood that ecological changes associated with changes to the foodweb and water clarity have altered some of these historical 'fish-flow' relationships (see below).

***The Changing Relationships Between Delta Outflow and Habitat Suitability in the Low-Salinity Zone:*** A second source of scientific uncertainty that fosters differing opinions about the utility of managed Delta outflow is the gradual decoupling of several key estuarine habitat features from Delta outflow (DFG 2010; Figure 9). These include a step-decline in the frequency with which the 2 psu salinity isohaline interacts with Suisun Bay starting in 1977, a step-decline in the abundance of mysid shrimp starting in 1987, proliferation of submerged plants starting in the 1980s, and a sudden clearing of estuary waters starting in 1999. These factors are each discussed in more detail below, but we note that during this period of abrupt habitat changes, the estuary has become increasingly invaded and dominated by non-native species (Nichols et al. 1990; Cohen and Carlton 1998; Brown and Michniuk 2007; Kimmerer et al. 2008). It was recently hypothesized that this recent sequence of species invasions was enabled by the ecosystem stress caused by natural drought periods exacerbated by water management (Winder et al. 2011).

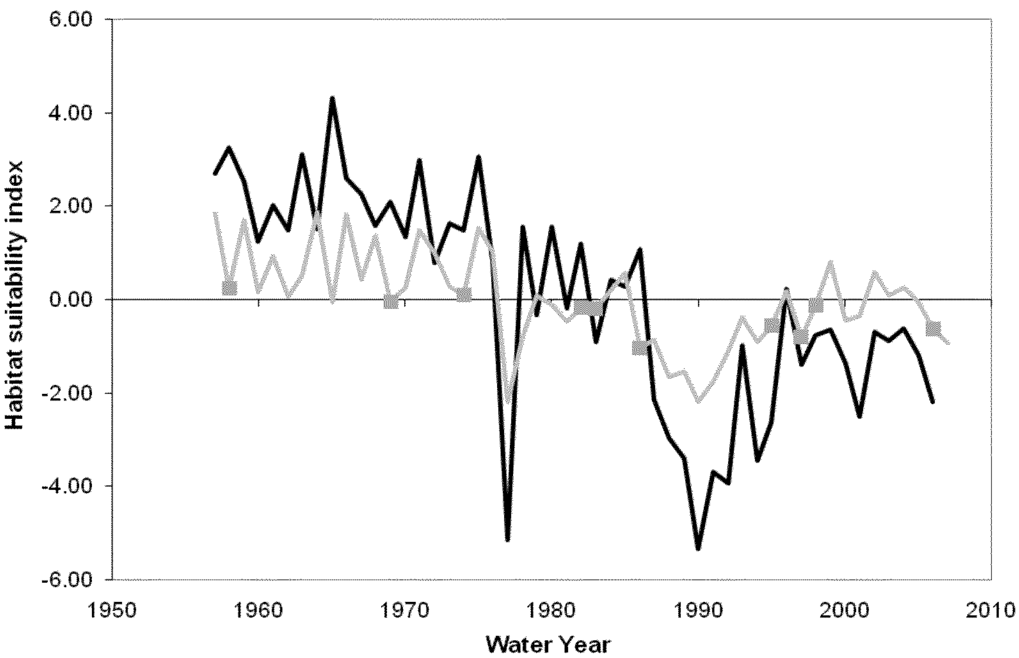


**Figure 9. Gray line: normalized time series of the number of days X2 was no more than 74 km from the Golden Gate Bridge per water year divided by the 8-River index of unimpaired flow. Black line: a normalized multifactor estuarine habitat suitability index including the data comprising the gray line plus data on mysid shrimp density and Sacramento River sediment supply. The pink boxes show the 10 wettest years in the time series. See DFG (2010) for details.**

The San Francisco Estuary has been continually modified for more than 150 years, but we mentioned several changes that have been observed during the comprehensive monitoring of the ecosystem that has occurred over the past 15-35 years. The first was a step-decline in the frequency with which X2 overlaps Suisun and San Pablo bays that started in the extreme drought year of 1977 (Figure 9). The gray line in Figure 9 is a normalized time series of days in each water year (October-September) that X2 was less than or equal to 74 km from the Golden Gate Bridge, divided by the 8-River index of unimpaired runoff for that water year. Dividing by the 8-River index removes the variability in X2 location that is due to how wet or dry a year was. This change has been most noticeable during the fall (Feyrer et al. 2007) and most planning models indicate this upstream shift of the low-salinity zone will continue (Feyrer et al. 2011).

The second change to fish-flow linkages in the estuary coincided with the invasion of the overbite clam, which contributed to changes in the composition and function of the estuary's food web (Alpine and Cloern 1992; Kimmerer et al. 1994; Orsi and Mecum 1996; Kimmerer 2002; Kimmerer et al. 2008). The third change was a decrease in the turbidity of estuarine water that has occurred as Gold Rush-era sediment finished washing out to the ocean (Schoellhamer 2011). The construction of dams and armored levees throughout the Sacramento and San Joaquinwatersheds, in conjunction with active management of soil runoff, has caused sediment inputs to the estuary to greatly decrease (Wright and Schoellhamer 2004; 2005). Although this reduction of sediment can be seen as beneficial for consumptive uses, turbidity is well known to strongly affect fish assemblage structure around the world (Blaber and Blaber 1980; Cyrus and Blaber 1987; Rodríguez and Lewis 1997; Quist et al. 2004). The reason is simple; some fish are adapted to use turbid water environments and some are not. Thus, if an ecosystem changes from turbid to clear or vice versa, its fish fauna will change too. There is a considerable gradient of water clarity across the Delta and the nearshore fish assemblages reflect that gradient (Nobriga et al. 2005).



In addition to declining sediment supply, in the mid-1980s the Delta was invaded by *Egeria densa*, an aquatic macrophyte that has taken hold in many shallow habitats (Brown and Michnuik 2007; Hestir 2010). The large canopies formed by non-native submerged aquatic vegetation (SAV) promote sedimentation of particulate matter from the water column which increases local water transparency. Dense SAV canopies also provide habitat for a suite of non-native fishes that have displaced native fishes throughout the western U.S. and similar climates in Europe (Aparicio et al. 2000; Olden et al. 2006; Light and Marchetti 2007). Finally, SAV colonization over the last three decades has led to a shift in the dominant trophic pathways to fishes (Grimaldo et al. 2009b). The SAV food web is an insular, nearshore food web that does not seem to exchange strongly with nearby pelagic habitats. This means that the Delta is currently very productive – but the new SAV-based food web is largely unavailable to the BDCP target fishes that are more reliant on the historical food web.

Most climate-change scenarios for California's Sacramento–San Joaquin Delta forecast increased temperatures (Dettinger 2005; Wagner et al. 2011). The resulting long-term (50-year) effects of increased air and water temperatures will increase the ecosystem's physiological rates, and will physiologically challenge the BDCP target fishes. Higher water temperatures can be problematic for the survival of several BDCP target fishes (Baker et al. 1995; Marine and Cech 2004; Lindley et al. 2006; Bennett et al. 2008; Nobriga et al. 2008, Wagner et al. 2011). Water temperatures may be a significant stressor that increasingly offsets the benefits of high Delta outflow, and exacerbates the ecological problems associated with low Delta outflow in the coming decades (Brown et al. submitted manuscript).

***Evolution of Technical Expert Thinking About How Delta Outflow Criteria Need to Work to Protect the BDCP Target Fishes*:** There are two present-day water operations rules for Delta outflow: a State-mandated rule that has been implemented each February-June since 1995 per D-1641 (SWRCB 1995); and a September-November rule that was part of USFWS' (2008) biological opinion. The former was proposed to continue as part of the *Steering Committee's February 2010 Preliminary Proposal*; the latter was not. The State's Port Chicago (Roe Island) rule can require steady-state outflows up to 29,200 cfs for several consecutive months when watershed precipitation is very high. It more commonly requires steady-state outflows closer to 11,400 cfs, which maintains X2 at Chipps Island. The USFWS' 2008 biological opinion can require X2 to be located as far downstream as Chipps Island during the fall.

In 2011 the Bureau of Reclamation drafted an Adaptive Management Plan (AMP) for the USFWS fall X2 requirement. The AMP document provides a layered conceptual model describing hypothesized interactions of fall Delta outflow with abiotic and biotic attributes of delta smelt habitat and their possible influence on delta smelt carrying capacity. As in any AMP, the goal is to carefully study the response of delta smelt to fall flow management actions to determine whether the existing RPA prescription works as expected, or, if not, what if any fall Delta outflow prescription can reliably provide protective benefits to delta smelt with a minimum impact to water supply. It is possible that the outcomes of the AMP studies may suggest the need for fall flow actions that differ from the action described in USFWS (2008). This potential array of alternative fall actions could range from no fall flow action at all to an action that is more expansive than that which is presently prescribed. Since the development of USFWS (2008), the triggering requirements laid out in the Fall Outflow RPA (X2 at 74 km in September-October) have occurred and were met in fall 2011. Thus, most of the data collected as part of this first iteration of the AMP have not yet been reported on. Variations of the SWRCB (1995) Delta outflow standard were explored during the 2009 development of the BDCP (Table 10). The Technical Team did not have time to fully explore these variations. That said, the results showed that interannual variation in hydrology had a larger influence on X2 than operational scenarios or projected sea-level rise (Figure 10). Model results for February-June X2 varied 18-21 km among water-year types within individual scenarios, compared to 5-7 km among scenarios within any given water-year type. The Preliminary Proposal modeling indicated that the climate change effect on X2 due to sea-level rise is on the order of 2-4 km. Note that Table 10 does not show the within-year variation in predicted X2 locations. During February-March, X2 can be up to 17-25 km further downstream than in June (BDCP 2011). Thus, the modeled intra-annual variation is comparable to the variation among water-year types.

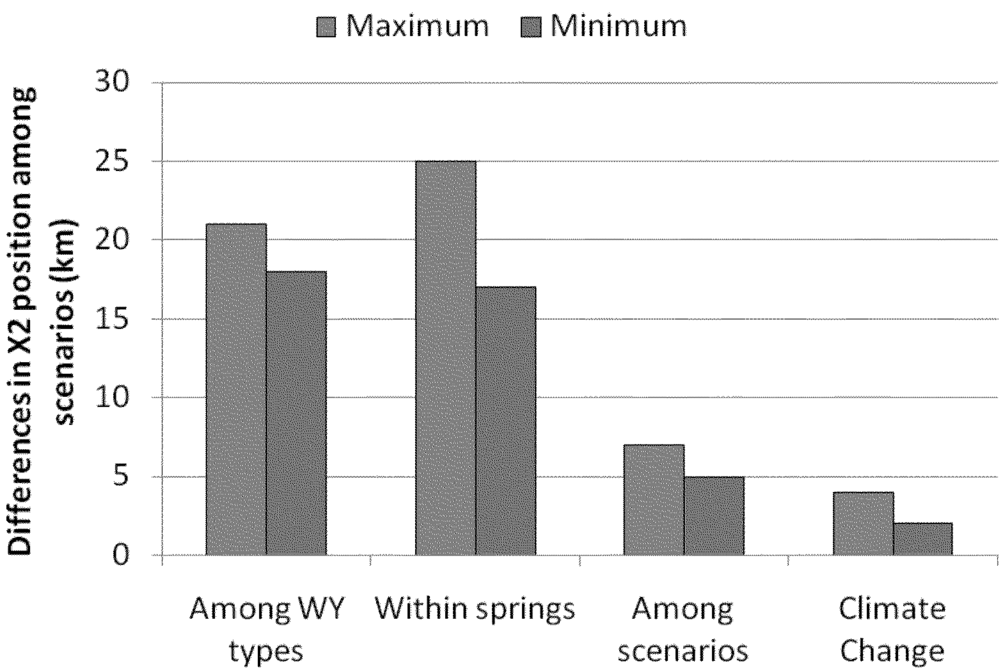


**Figure 10. Maximum and minimum variation in monthly mean X2 locations (February-June), based on the waypoints in Table 10.**

**Table 10. Summary of NGO explorations for revision of springtime X2 rules. Data source: 090520_-_Long-Term_Operations_-_Concepts_for_BDCP.pdf. Data in the table are average February-June location of X2 (km from Golden Gate Bridge) by water-year type based on CalLite modeling, and equivalent results compiled from Appendix E3, February 2011 based on CALSIM-2 modeling with its retrained artificial neural network and built-in climate change and habitat restoration parameters.**

| *2009 NGO Gaming Scenarios* | *Basic description* | *Wet* | *AN* | *BN* | *Dry* | *Crit* |
|---|---|---|---|---|---|---|
| D-1641 | SWRCB (1995) | 60 | 65 | 70 | 75 | 79 |
| BDCP/DRERIP #1 | | 61 | 66 | 71 | 75 | 79 |
| NGO X2 | X2 linked to 8-River Index with storage offramps to prevent excessive reservoir draw-down | 59 | 65 | 70 | 74 | 79 |
| Proportionate Outflow Approach | 50% of unimpaired Sacramento Valley runoff and 100% of impaired San Joaquin Valley runoff | 60 | 65 | 70 | 74 | 79 |
| Proportionate Reservoir Release Approach | Normal distribution of reservoir release percentages with flow caps and storage offramps to prevent excessive reservoir draw-down | 61 | 66 | 71 | 75 | 80 |
| ***February 2011 Steering Committee Preliminary Proposal comparisons*** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Environmental Base Condition | South Delta diversions; Biological Opinions in place | 61 | 65 | 71 | 73 | 82 |
| EBC Early Long-term | South Delta diversions; Biological Opinions in place; predicted operations around 2025 | 62 | 66 | 72 | 76 | 82 |
| EBC Late Long-term | South Delta diversions; Biological Opinions in place; predicted operations around 2060 | 65 | 67 | 74 | 77 | 83 |
| Preliminary Proposal | Dual conveyance; Steering Committee February 2010 operations | 63 | 68 | 73 | 77 | 82 |
| PP Early Long-term | Dual conveyance; Steering Committee estimated operations around 2025 | 64 | 68 | 74 | 77 | 83 |
| PP Late Long-term | Dual conveyance; Steering Committee estimated operations around 2060 | 66 | 70 | 76 | 79 | 84 |

The intra-annual variation in Delta outflow is potentially important to the development of adaptive waypoints. Delta outflows during the spring (April-June) are stored and diverted relative to hypothetical unimpaired river flows more so than winter flows (Kimmerer 2002a; TBI 2010). This is the case for three primary reasons. First, flood storage rules become less restrictive from winter into spring so reservoirs can maintain water levels closer to their storage capacities. Second, the Projects need to store water to meet coldwater pool targets that support salmonid fisheries below the Project dams (NMFS 2009). The coldwater stored during spring is usually released into the rivers during summer-fall to combat high air temperatures. Third, irrigation water demand in the Sacramento Valley and the Delta increases in the spring, which affects how much of the river flow released from Project reservoirs is available for Delta outflow and south-of-Delta export.

The potential for positive effects of April-June Delta outflow exists for all BDCP target fishes (Table 2). However, there are three fishes for which discernable spring outflow-population dynamic linkages have been made: longfin smelt, Chinook salmon, and white sturgeon. During 2010, the SWRCB conducted proceedings related to establishing Delta outflow criteria. The Bay Institute's Exhibit 2 submitted to the proceedings contains analyses that could provide a conceptual basis for establishing a March through May high-protection adaptive range bookend for longfin smelt (Rosenfield and Swanson 2010). The analysis indicates that a total March through May outflow of approximately six million acre-feet is a threshold above which year-on-year population growth tends to be positive, and below which population growth is generally negative. Since the analysis used data from the period 1988 through 2007 when food supplies would have been impaired by the establishment of the overbite clam, this may represent the level of outflow required to recover longfin smelt in the absence of a positive population response to other BDCP conservation efforts. A total March-May outflow of six million acre-feet corresponds to an average outflow rate during this period of approximately 35,000 cfs, which could be adjusted month to month so that monthly average rates during the period mimic the relative distribution of unimpaired flows.

Other waypoints for springtime flows include April-June Delta outflows of approximately 20,000 cfs. This flow rate is correlated with successful juvenile Chinook salmon passage through the Delta (e.g., Kjelson and Brandes 1989) and white sturgeon recruitment (Fish 2010). The covariation of water temperature and flow influences on Chinook salmon survival has been noted several times (Kjelson et al. 1982; Baker et al. 1995; Newman and Rice 2002). Thus, it is possible that Sacramento River flow is a surrogate for one or more mechanisms causing mortality of young salmon, rather than a fundamentally necessary habitat attribute. For instance, river inflows covary with high turbidity as well as cool water temperature, both of which can reduce the vulnerability of juvenile salmon to predators (Gregory and Levings 1998; Marine and Cech 2004). The Delta outflows needed to produce particular biological benefits are also confounded by the hydrologic covariation of flows from one month to the next during native fish reproductive and migration seasons in the winter-spring, and further confounded by how much cumulative benefit has accrued to fishes as flows move through the watershed. Scientists will continue to try to better understand the mechanistic linkages between flow and fish production to increase the predictability of management outcomes. But for now, these are uncertainties that may need to be managed adaptively. The following describes the rationale for a suggested additional waypoint or waypoints for April-June Delta outflow thresholds.

We summarized modeled monthly average Delta outflow data for April-June for two water diversion configurations based on the early long-term time frame (Figure 11). Note that all of the scenarios we summarized conformed to the SWRCB (1995) Delta outflow standard. The data indicate that flows meeting the longfin smelt threshold will occur too infrequently to reliably increase population abundance over time. Most longfin smelt live two years (Rosenfield and Baxter 2007), but the recurrence interval of a flow ≥ 35,000 cfs is only about one in four years for April and less than one in twenty years in June. The Preliminary Proposal is predicted to affect this result by 0-5% depending on the month. Thus, it does not appear that spring flows can be managed to recover longfin smelt without compromising other water storage or diversion goals.

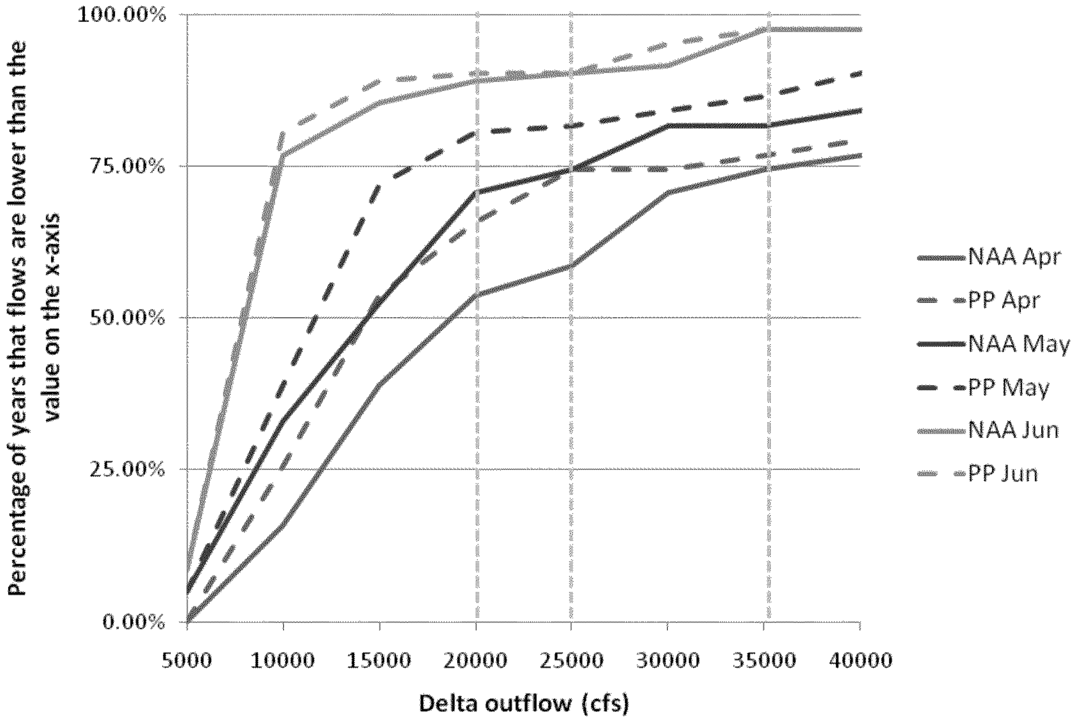


**Figure 11. Cumulative distribution of modeled Delta outflows for April through June comparing the February 2010 Preliminary Proposal (PP) to a "no action alternative" (NAA) that has only South Delta diversions and fully implements the USFWS (2008) and NMFS (2009) RPAs. Note that all six modeled scenarios nominally meet the SWRCB (1995) Delta outflow standard. Flows greater than 40,000 cfs are comparatively rare and for clarity are not shown so that differences at 20,000 cfs, 25,000 cfs, and 35,000 cfs are more clear. These thresholds are shown as dashed gray vertical lines.**

The 20,000 cfs outflow waypoint is potentially more achievable via river flow management, except possibly in June when its recurrence interval is about once in ten years and essentially unaffected by Preliminary Proposal operations (Figures 11-12). A ten-year recurrence interval is not very useful to Chinook salmon, which only live three to four years, or other species of concern such as sturgeon, which typically spawn every two to four years (Moyle 2002). During April and May the modeled frequency of Delta outflow ≥ 20,000 cfs is strongly influenced by the proposed dual conveyance project configuration, and is predicted to occur up to 20% less often (Figure 12). The adaptive range should evaluate a 50% recurrence interval for April flows ≥ 20,000 cfs and a 33% recurrence interval for May (for all water year types combined). These are recurrence frequencies that are equal to the no action alternative scenarios (Figure 11). This will increase the likelihood that spring flows occur frequently enough to contribute to strong Chinook salmon and white sturgeon cohorts.

For white sturgeon, year class index (YCI) has been shown to be highly correlated with spring outflow

(CDFG 1992); green sturgeon dynamics show similar relationships to flow (Poytress et al. 2009). The AFRP recommended Delta outflows of 25,000 cfs in April and May (for Wet and Above-Normal water-year types) to achieve strong white sturgeon year classes (USFWS 1995). The AFRP recommendations highlight key locations along the Sacramento River that, when flow thresholds have been met, provide a continuous flow signal from estuary to spawning grounds. Delta outflow is the location most impacted by dual conveyance (Figure 12) as the other locations along the Sacramento River that were evaluated by USFWS (1995) are located upstream of the proposed North Delta diversions.

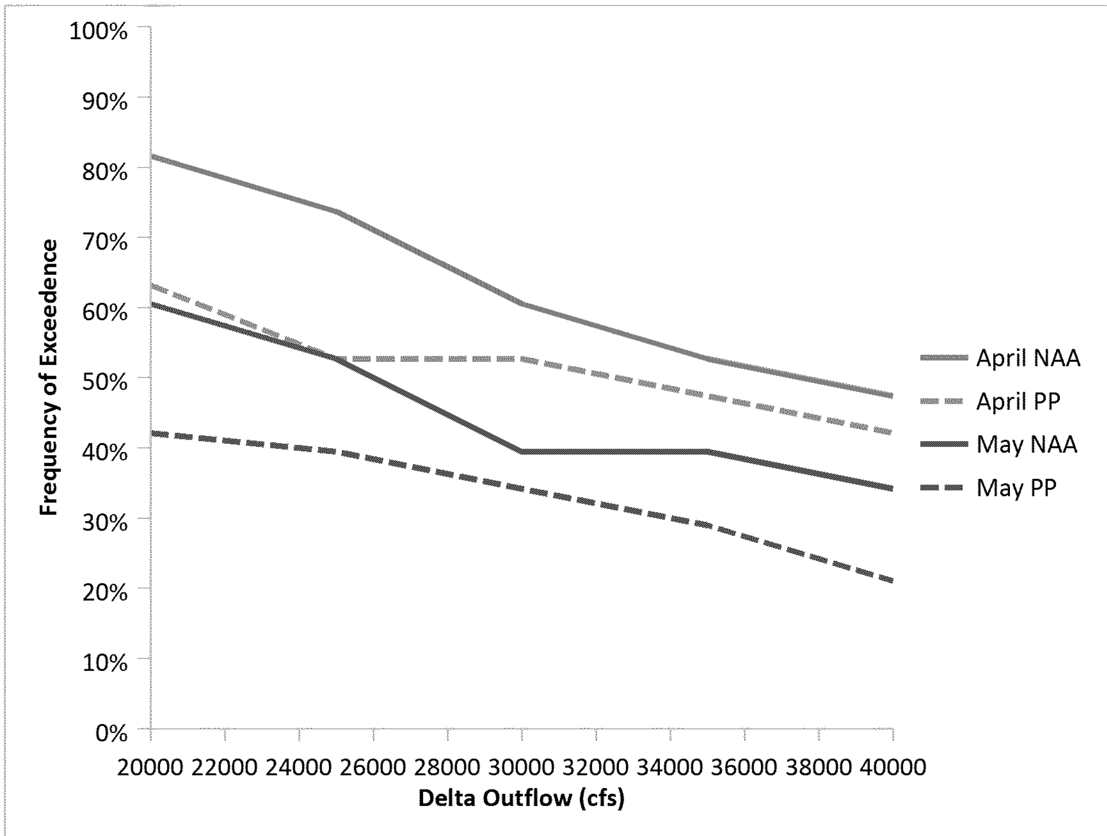


**Figure 12. Exceedence frequency of April and May mean Delta outflows under existing conditions (NAA) and preliminary proposal (PP) operations for Wet and Above Normal water-year types.**

***Export to Inflow Ratios*:** The Technical Team did not develop an adaptive range around the State of California D-1641 standard on the ratio of total Delta exports to total Delta inflows. However, the Team chose to highlight that there is an alternative method to the CALSIM-II modeling assumptions used to calculate the Delta E/I ratio for the preliminary proposal. The preliminary proposal water operations have been created and modeled with an E/I ratio that measures inflow from the Sacramento River below the North Delta diversions (instead of at Freeport), and does not include water diverted via the North Delta diversions as exports from the Delta. Using this method, model summaries developed to date for the preliminary proposal do not show any exceedances of the D-1641 standard. Alternatively, the Delta E/I ratio could be calculated using inflow measured at Freeport, and count combined north and south Delta diversions as exports. Using this method, there are several years when the current D-1641 standard would be exceeded under the preliminary proposal (Figure 13). These exceedances are most common in May and June, months that include the peak of fall-run Chinook salmon emigration through the Delta (Kjelson et al. 1982; NMFS 2009) and are important months for migration and rearing of most of the other BDCP target fishes as well (Table 2).

When the Delta E/I ratio is near its current limit of 35% in key migratory months, Delta hydrodynamics are heavily influenced by export operations (Kimmerer and Nobriga 2008). Under dual conveyance, reduced Sacramento River flow could impact water velocity, turbidity, predator-prey dynamics, residence or migratory travel time, and the susceptibility of entrainment into the Central and Southern Delta via Georgiana Slough, Three-Mile Slough, and the confluence of the Sacramento and San Joaquin Rivers.

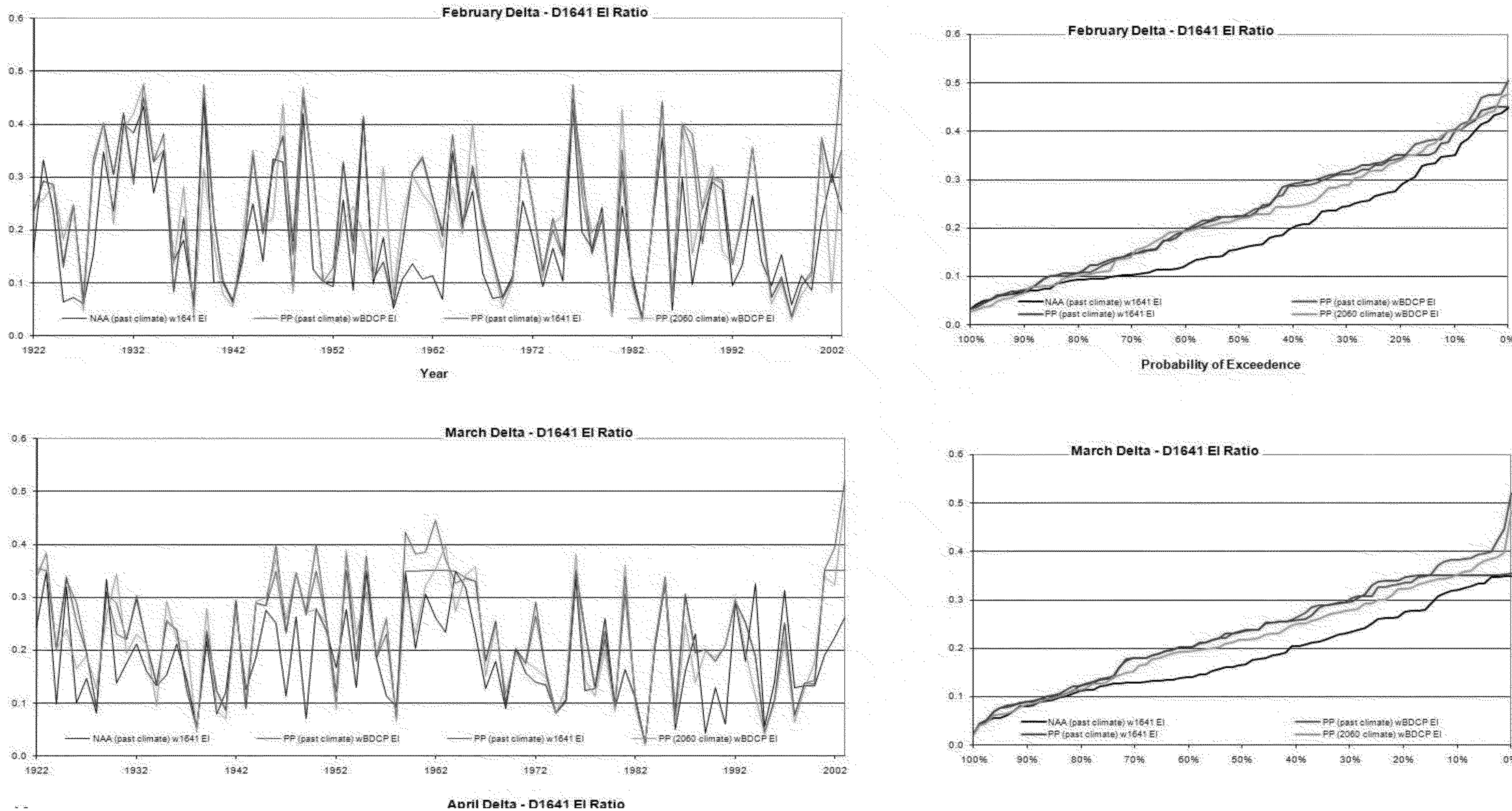


**Figure 13. CALSIM-II modeling of Export to Inflow ratios as operated under Baseline, BDCP and BDCP with adoption of D-1641 standard. Note that ratios higher than 0.35 exceed the current State of California standard.**

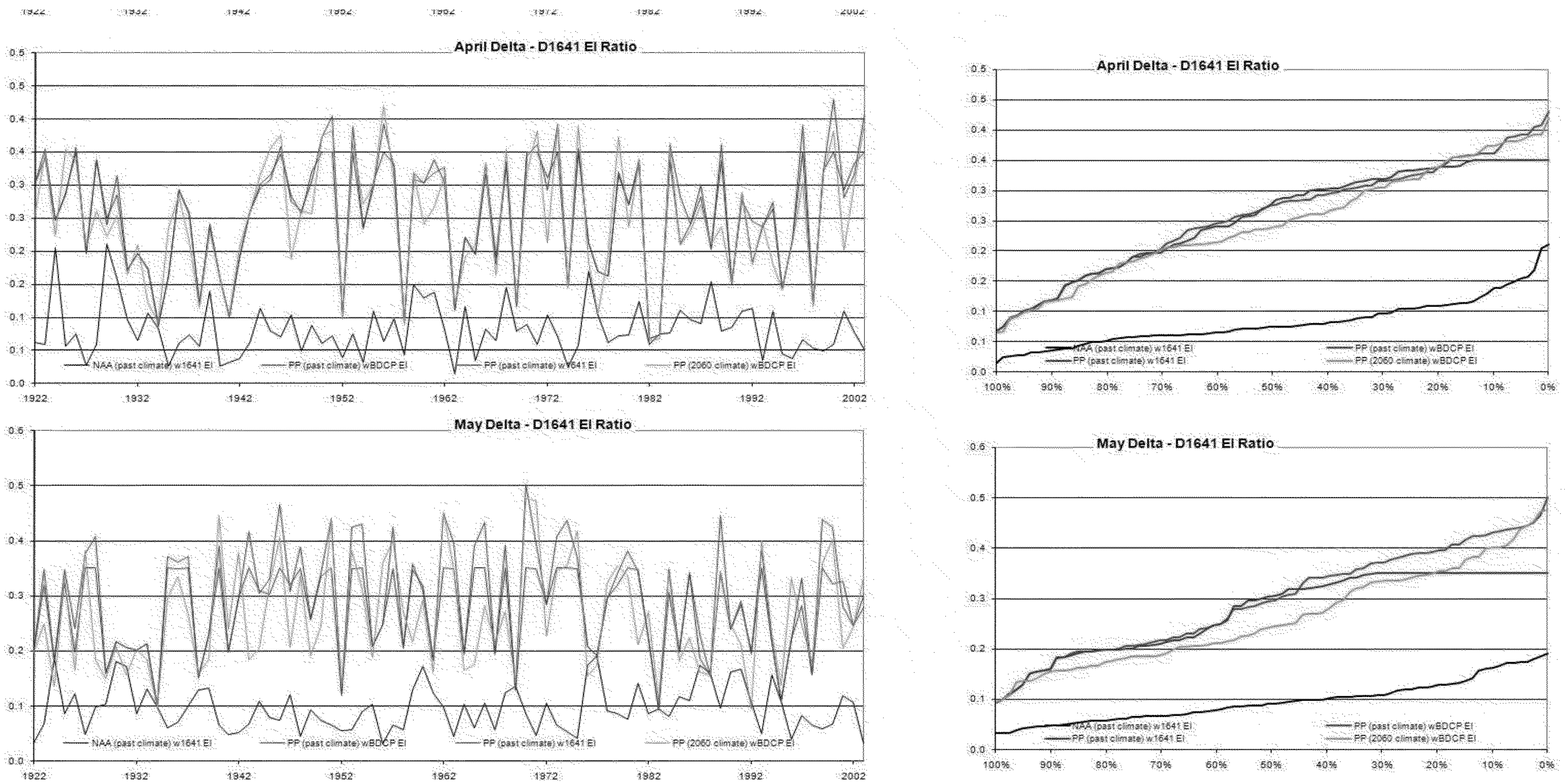


**Figure 14. CALSIM-II modeling of Export to Inflow ratios as operated under Baseline, BDCP and BDCP with adoption of D-1641 standard.**

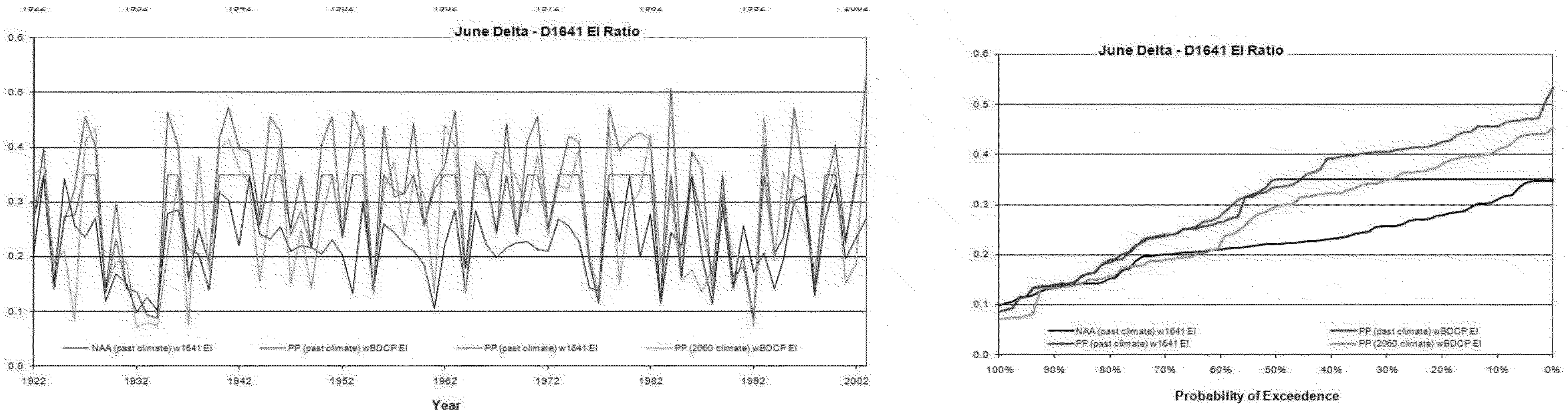


**Figure 15**. **CALSIM-II modeling of Export to Inflow ratios as operated under Baseline, BDCP and BDCP with adoption of D-1641 standard.**

***Summary and Recommendations:*** As part of the BDCP adaptive management program, adjustments to the water operations criteria will likely be necessary and advisable. This "adaptive range" of water operations will contribute to the operational and institutional flexibility needed to respond to changed circumstances and unforeseen biological outcomes, and will improve the effectiveness of the BDCP over time. The adaptive range will therefore span a range of water operations that could be recommended while implementing BDCP's adaptive management program, which will be linked to program goals and objectives (which are still in development). The goal of this science-based program will be to continually gain information on the extent to which adjustments in BDCP implementation (including water operations) contribute to changes in covered species population viability and ecosystem function.

Our summary of BDCP waypoints shows that for many operational parameters, the adaptive range may need to be quite broad to accommodate the maintenance or improvement of fish abundance, survival, growth, spatial distribution, and the function of supporting ecosystems. Climate change adds to the uncertainty about how the BDCP may affect species and their habitats. The BDCP's adaptive management framework will be focused on reducing uncertainty through fish, ecosystem, and operational experiments, which will be used to help design near- and long-term conservation measure actions that will attain the Plan's goals and objectives. Waypoints may be used as milestones for modifying water operations measures and for designing adaptive management experiments should the regulating agencies detect a significant response in the species' condition. Essential aspects of the adaptive management implementation plan should describe processes for transparency and scientific review in identifying biological triggers and operational waypoints within the adaptive range, issues resolution, and reporting.

The endpoints in this report bracket the most extreme waypoints for each of the water operations parameters the Technical Team evaluated. For the most part, the individual endpoints are existing proposals for which a documented rationale was previously proposed regarding covered species or habitat responses. The collection of endpoints for the different water operations parameters at either end of the range of waypoints does not represent a realistic management outcome for BDCP implementation any more than any other collection of waypoints within the range. **We do not recommend that the endpoints be considered operations scenarios to be modeled**. We see no utility in modeling or conducting effects analyses on the collections of endpoints because there is no basis for informing when, how often, and to what extent any individual endpoint would be implemented during the permitted life of the BDCP. The endpoints are reported for completeness; they show how much individual operations actions might need to vary, but as a set of operations rules, they are no more likely than any other collection of waypoints. In fact, with the implementation of the adaptive management program mentioned above, it is very unlikely that all of the water operations parameters would be at either endpoint simultaneously for the simple reason that it would be undesirable to change so many parameters simultaneously, because doing so would hinder opportunities to increase the scientific understanding of the target species. Thus, the results of modeling the suites of endpoints would artificially suggest the project would be very risky to species or extremely costly in water supply.

We also suggest that the BDCP not develop a final Adaptive Range until the plan has specific biological *objectives*. The range needed simply to maintain conditions or generate minor improvements is likely to be much narrower than an adpative range for a plan that proposes large improvements in species condition or status.

The Technical Team recommended some potential new waypoints that might be included in an adaptive range, including: April-June flows that go beyond D-1641; broader variation in diversions from the north vs. south Delta in July-September than has been modeled so far; changes to October-November DCC and South Delta operations; flows in the Yolo Bypass designed to improve fish passage; a longer duration pulse protection at the North Delta Diversions, and a comment on the calculation of the Delta E/I ratio under the BDCP. These potential new waypoints may warrant further analysis and discussion, beginning in the upcoming public workgroup.

***Potential Next Steps***:

An alternative approach to picking one or both endpoints as a single operation to be modeled for the BDCP might involve the construction of several hypothetical alternative scenarios, each consisting of a selection of waypoints from the "menu" laid out in this document. Based on current knowledge of species and ecosystems, the goal would be to pick a limited, but highly targeted subset of water operations parameters that would provide the best chance of improving the long-term status of a species or allow for additional exports with the confidence that doing so would constitute no additional risk to a species. These alternative scenarios would be examples of what an adaptive management response might look like, and would not be designed to be predetermined responses, as the real-world conditions would never match those in the scenario. It would also help us identify gaps in our knowledge of how specific stressors impact populations and habitats.

A key tool in evaluating these scenarios would be quantitative life-cycle models for the species of interest, which would be linked, conceptually and quantitatively, to variables including water operations parameters. This approach should be attempted with one or two examples to evaluate how linked models can best be used in a scenario planning framework for informing decision-making about species protection and water operations.

Until the quantitative life-cycle models needed for this type of scenario planning are available, we recommend that the next steps in developing an adaptive range for BDCP are: (1) Develop quantitative goals and objectives that can be fed into an Effects Analysis to determine their feasibility; (2) Complete an acceptable and effective Effects Analysis ; and (3) Develop an Adaptive Management Plan around key questions that the Effects Analysis cannot answer, with a focus on particularly controversial waypoints.

## *References Cited*


Adams, PB, Grimes, C, Hightower, JE, Lindley, ST, Moser, ML, Parsley, MJ. 200X. Population status of North American green sturgeon, *Acipenser medirostrus*. Environmental Biology of Fishes 79:339-356.

Alpine, AE, Cloern, JE. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limnology and Oceanography 37:946-955.

Anderson, JJ, Gurarie, E, Zabel, RW. 2005. Mean free-path length theory of predator-prey interactions: application to juvenile salmon migration. Ecological Modelling 186:196-211.

Aparicio, E, Vargas, MJ, Olmo, JM, de Sostoa, A. 2000. Decline of native freshwater fishes in a Mediterranean watershed on the Iberian Peninsula: a quantitative assessment. Environmental Biology of Fishes 59:11-19.

Arthur, JF, Ball, MD, Baughman, SY. 1996. Summary of Federal and State Water Project environmental impacts in the San Francisco Bay-Delta estuary, California. Pages 445-495 in Hollibaugh, JT (ed), San Francisco Bay: the ecosystem. American Association for the Advancement of Science, San Francisco.

Baker, PF, Speed, TP, Ligon, FK. 1995. Estimating the influence of temperature on the survival of Chinook salmon smolts (*Oncorhyncus tshawtscha*) migrating through the Sacramento-San Joaquin Delta of California. Canadian Journal of Fisheries and Aquatic Sciences 52:855-863.

Bennett, WA. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science 3:http://repositories.cdlib.org/jmie/sfews/vol3/iss2/art1.

Bennett, WA, Hobbs, JA, Teh, S. 2008. Interplay of environmental forcing and growth-selective mortality in the poor year-class success of delta smelt in 2005. Final Report to the Interagency Ecological Program.

Blaber, SJM, Blaber, TG. 1980. Factors affecting the distribution of juvenile estuarine fish and inshore fish. Journal of Fish Biology 17:143-162.

Brandes, PL, McLain, JS. 2001. Juvenile Chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. p. 39-138 in Brown, R (ed), Department of Fish and Game Fish Bulletin 179, Contributions to the biology of Central Valley salmonids, volume 2.

Brown, LR, Kimmerer, W, Brown, R. 2009. Managing water to protect fish: a review of California's Environmental Water Account, 2001-2005. Environmental Management 43:357-368.

Brown, LR, Michniuk, D. 2007. Littoral fish assemblages of the alien-dominated Sacramento-San Joaquin Delta, California, 1980-1983 and 2001-2003. Estuaries and Coasts 30:186-200.

Brown, LR, Moyle, PB. 2005. Native fishes of the Sacramento-San Joaquin drainage, California: a history of decline. American Fisheries Society Symposium 45:75-98.

Brown, LR. 2000. Fish communities and their associations with environmental variables, lower San Joaquin River drainage, California. Environmental Biology of Fishes 57:251-269.

California Department of Fish and Game. 1992. Sturgeon in Relation to Water Development in the Sacramento-San Joaquin Esturary. Exhibit 28, for the State Water Resources Control Board Water Rights Phase of the Bay-Delta Estuary Hearings.

Carlisle, DM, Wolock, DM, Meador, MR. 2010. Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment. Frontiers in Ecology and the Environment; doi 10.18890/100053.

CH2M HILL. 2009a. Representation of National Marine Fisheries Service Biological Opinion Reasonable and Prudent Alternative actions for CALSIM-2 planning studies – DRAFT [v13] November 3, 2009.

CH2M HILL. 2009b. Representation of U.S. Fish and Wildlife Service Biological Opinion Reasonable and Prudent Alternative actions for CALSIM-2 planning studies – DRAFT [v33] November 2, 2009.

Chigbu, P, Sibley, TH, Beauchamp, DA. 1998. Abundance and distribution of *Neomysis mercedis*, and a major predator, longfin smelt (*Spirinchus thaleichthys*) in Lake Washington. Hydrobiologia 386:167-182.

Cohen, AN, Carlton, JT. 1998. Accelerating invasion rate in a highly invaded estuary. Science 279:555-558.

Coutant, C. C., and R. R. Whitney. 2000. Fish behavior in relation to passage through hydropower turbines: a review. Transactions of the American Fisheries Society 129:351-380.

Cyrus, DP, Blaber, SJM. 1987. The influence of turbidity on juvenile marine fish in the estuaries of Natal, South Africa. Continental Shelf Research 7:1411-1416.

Dege, M, Brown, LR. 2004. Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco Estuary. American Fisheries Society Symposium 39:49-66.

Deriso, RB. 2011. Declaration of Dr. Richard B. Deriso in support of Plaintiff's motion for injunctive relief, Case 1:09-cv-00407-OWW-DLB, Document 772, filed 1/28/2011.

Dettinger, MD. 2005. From climate-change spaghetti to climate-change distributions for 21st Century California. San Francisco Estuary and Watershed Science 3:http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art4.

DFG (Department of Fish and Game). 2009. California Endangered Species Act Incidental Take Permit No. 2081-2009-001-03, Department of Water Resources, California State Water Project Delta Facilities and Operations.

Drinkwater, KF, Frank, KT. 1994. Effects of river regulation and diversion on marine fish and invertebrates. Aquatic Conservation: Marine and Freshwater Research 4:135-151.

Dugdale, RC, Wilkerson, FP, Hogue, VE, Marchi, A. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal, and Shelf Science 73:17-29.

Feyrer, F, Newman, K, Nobriga, M, Sommer, T. 2011. Modeling the effects of future outflow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts 34:120-128.

Feyrer, F, Nobriga, ML, Sommer, TR. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734.

Feyrer, F, Sommer, T, Harrell, W. 2006a. Managing floodplain inundation for native fish: production dynamics of age-0 splittail (*Pogonichthys macrolepidotus*) in California's Yolo Bypass. Hydrobiologia 573:213-226.

Feyrer, F, Sommer, T, Harrell, W. 2006b. Importance of flood dynamics versus intrinsic physical habitat in structuring fish communities: evidence from two adjacent engineered floodplains on the Sacramento River, California. North American Journal of Fisheries Management 26:408-417.

Feyrer, F, Sommer, TR, Baxter, RD. 2005. Spatial-temporal distribution and habitat associations of age-0 splittail in the lower San Francisco Estuary watershed. Copeia 2005:159-168.

Fish, MA. 2010. A white sturgeon year-class index for the San Francisco Estuary and its relation to Delta outflow. Interagency Ecological Program Newsletter 23(2):80-84.

Flannery, MS, Peebles, EB, Montgomery, RT. 2002. A percent-of-flow approach for managing reductions of freshwater inflows from unimpounded rivers to southwest Florida estuaries. Estuaries 25:1318-1332.

Gaines, P.D. and C.D. Martin. 2001 (draft). Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River. Red Bluff Research Pumping Plant Report Series, Volume 14. U.S. Fish and Wildlife Service, Red Bluff, California.

Ger, KA, Teh, SJ, Goldman, CR. 2009. Microcystin L-R toxicity on dominant copepods *Eurytemora affinis* and *Pseudodiaptomus forbesi* of the upper San Francisco Estuary. Science of the Total Environment 407: 4852-4857.

Greenfield, BK, The, S, Ross, JRM, Hunt, J, Zhang, GH, Davis, JA, Ichikawa, G, Crane, D, Hung, SSO, Deng, DF, The, F-C, Green, PG. 2008. Contaminant concentrations and histopathological effects in Sacramento splittail (*Pogonichthys macrolepidotus*). Archives of Environmental Contamination and Toxicology DOI 10.1007/s00244-007-9112-3.

Gregory, RS, and C.D. Levings. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Transactions of the American Fisheries Society 127:275-285.

Grimaldo, LF, Sommer, T, Van Ark, N, Jones, G, Holland, E, Moyle, P, Smith, P, Herbold, B. Factors affecting fish entrainment into massive water diversions in a freshwater tidal estuary: can fish losses be managed? North American Journal of Fisheries Management 29:1253-1270.

Grimaldo, LF, Stewart, AR, Kimmerer, WJ. 2009. Dietary segregation of pelagic and littoral fish assemblages in a highly modified tidal freshwater estuary. Marine Coastal Fisheries: Dynamics, Management, and Ecosystem Sciences 1:200-217.

Harrell, W.C. and T.R. Sommer. 2003. Patterns of Adult Fish Use on California's Yolo Bypass Floodplain. Pages 88-93 in P.M. Faber, editor. California riparian systems: Processes and floodplain management, ecology, and restoration. 2001 Riparian Habitat and Floodplains Conference Proceedings, Riparian Habitat Joint Venture, Sacramento, California.

Hestir, E. 2010. Trends in estuarine water quality and submerged aquatic vegetation invasion. PhD dissertation, University of California, Davis.

Hobbs, JA, Bennett, WA, Burton, J, Gras, M. 2007. Classification of larval and adult delta smelt to nursery areas by use of trace elemental fingerprinting. Transactions of the American Fisheries Society 136:518-527.

Hobbs, JA, Bennett, WA, Burton, J. 2006. Assessing nursery habitat quality for native smelts (*Osmeridae*) in the low-salinity zone of the San Francisco Estuary. Journal of Fish Biology 69:907-922.

Hobbs, JA, Lewis, LS, Ikemiyagi, N, Sommer, T, Baxter, RD. 2010. The use of otolith strontium isotopes ($^{87}Sr/^{86}Sr$) to identify nursery habitat for a threatened estuarine fish. Environmental Biology of Fishes 89:557-569.

Heublein, JC, Kelly, JT, Crocker, CE, Klimley, AP, Lindley, ST. 2009. Migration of green sturgeon, *Acipenser medirostrus*, in the Sacramento River. Environmental Biology of Fishes 84:245-258.

Jassby, A. 2008. Phytoplankton in the upper San Francisco Estuary: recent biomass trends, their causes, and their trophic significance. San Francisco Estuary and Watershed Science 6: Issue 1 [], article 2.

Jassby, AD, Cloern, JE, Cole, BE. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnology and Oceanography 47:698-712.

Jassby, AD, Kimmerer, WJ, Monismith, SG, Armor, C, Cloern, JE, Powell, TM, Schubel, JR, Vendlinski, TJ. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5:272-289.

Kimmerer, W, Brown, L, Culberson, S, Moyle, P, Nobriga, M, Thompson, J. 2008. Aquatic ecosystems. Pages 73-102 in Healey, M, Dettinger, M, Norgaard, R (eds). The state of Bay-Delta science, 2008. CALFED Science Program, Sacramento, CA.

Kimmerer, WJ, Gartside, E, Orsi, JJ. 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. Marine Ecology Progress Series 113:81-93.

Kimmerer, WJ, Nobriga, ML. 2008. Investigating particle transport and fate in the Sacramento-San Joaquin Delta using a particle tracking model. San Francisco Estuary and Watershed Science 6: Issue 1 [February 2008], article 4.

Kimmerer, WJ. 2002a. Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. Estuaries 25:1275-1290.

Kimmerer, WJ. 2002b. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology Progress Series 243:39-55.

Kimmerer, WJ. 2004. Open-water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science 2: Issue 1 [], article 1.

Kimmerer, WJ. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 6: Issue 2 [June 2008], article 2.

Kimmerer, WJ. 2011. Modeling delta smelt losses at the South Delta export facilities. San Francisco Estuary and Watershed Science 9: Issue 1 [April 2011], article 6.

Kjelson, MA, Brandes, PL. 1989. The use of smolt survival estimates to quantify the effects of habitat changes on salmonid stocks in the Sacramento-San Joaquin rivers, California. Pages 100-115 in Levings, CD, Holtby, LB, Henderson, MA (eds), Proceedings of the National workshop on effects of habitat alteration on salmonid stocks. Canadian Special Publication of Fisheries and Aquatic Sciences 105.

Kjelson, MA, Raquel, PF, Fisher, FW. 1982. Life history of fall-run juvenile Chinook salmon, *Oncorhyncus tshawytscha*, in the Sacramento-San Joaquin estuary, California. Pages 393-411 in Kennedy, VS (ed), Estuarine comparisons. Academic Press, New York.

Kohlhorst, DW, Botsford, LW, Brennan, JS, Calliet, GM. 1991. Aspects of the structure and dynamics of an exploited central California population of white sturgeon (*Acipenser transmontanus*). Pages 277-293 in Williot, P (ed), Acipenser, actes du premier colloque international sur l'esturgeon. CEMAGREF, Bordeaux, France.

Lehman, PW, Boyer, G, Satchwell, M, Waller, S. 2008. The influence of environmental conditions on the seasonal variation of *Microcystis* cell density and microcystins concentration in San Francisco Estuary. Hydrobiologia 600:187-204.

Lehman, PW, Sevier, J, Guilianotti, J, Johnson, M. 2004. Sources of oxygen demand in the lower San Joaquin River, California. Estuaries 27:405-418.

Lehman, PW, Sommer, T, Rivard, L. 2008. The influence of floodplain habitat on the quantity and quality of riverine phytoplankton carbon produced during the flood season in San Francisco Estuary. Aquatic Ecology 42:363-378.

Lehman, PW, Teh, SJ, Boyer, GL, Nobriga, ML, Bass, E, Hogle, C. 2010. Initial impacts of *Microcystis aeruginosa* blooms on the aquatic foodweb in the San Francisco Estuary. Hydrobiologia 600:229-248.

Light, T, Marchetti, MP. 2007. Distinguishing between invasions and habitat changes as drivers of diversity loss among California's freshwater fishes. Conservation Biology 21:434-446.

Lindley, ST, and 25 coauthors. 2009. What caused the Sacramento River fall Chinook stock collapse? Pre-publication report to the Pacific Fishery Management Council, dated March 18, 2009. http://swfsc.noaa.gov/uploadedFiles/Operating_units/FED/Salmon_decline_report_March_2009.pdf

Lindley, ST, Erickson, DL, Moser, ML, Williams, G, Langness, O, McCovey, BW Jr, Belchik, M, Vogel, D, Pinnix, W, Kelly, JT, Heublein, JC, Klimley, AP. 2011. Electronic tagging of green sturgeon reveals population structure and movement among estuaries. Transactions of the American Fisheries Society 140:108-122.

Lindley, ST, Moser, ML, Erickson, DL, Belchik, M, Welch, DW, Rechisky, EL, Kelly, JT, Heublein, J, Klimley, AP. 2008. Marine migration of North American green sturgeon. Transactions of the American Fisheries Society 137:182-194.

Linville, RG, Luoma, SN, Cutter, L, Cutter, GA. 2002. Increased selenium threat as a result of invasion of the exotic bivalve Potamocorbula amurensis into the San Francisco Bay-Delta. Aquatic Toxicology 57:51-64.

Loneragan, NR. 1999. River flows and estuarine ecosystems: implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. Australian Journal of Ecology 24:431-440.

MacFarlane, R. B., and E. C. Norton. 2002. Physiological ecology of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) at the southern end of their distribution, the San Francisco estuary and Gulf of the Farallones, California. Fisheries Bulletin 100:244-257

Mac Nally, R, Thompson, JR, Kimmerer, WJ, Feyrer, F, Newman, KB, Sih, A, Bennett, WA, Brown, L, Fleishman, E, Culberson, SD, Castillo, G. 2010. An analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modelling (MAR). Ecological Applications 20:1417-1430.

Marchetti, MP, Moyle, PB. 2001. Effects of flow regime on fish assemblages in a regulated California stream. Ecological Applications 11:530-539.

Marine, KR, Cech, JJ, Jr. 2004. Effects of high water temperature on growth, smoltification, and predator avoidance in juvenile Sacramento River Chinook salmon. North American Journal of Fisheries Management 24:198-210.

Matern, SA, Moyle, PB, Pierce, LC. 2002. Native and alien fishes in a California estuarine marsh: twenty-one years of changing assemblages. Transactions of the American Fisheries Society 131:797-816.

Maunder, MN, Deriso, RB. 2011. A state-space multi-stage life cycle model to evaluate population impacts in the presence of density-dependence: illustrated with applications to delta smelt (*Hypomesus transpacificus*). Canadian Journal of Fisheries and Aquatic Sciences 68:1285-1306.

May, JT, Brown, LR. 2002. Fish communities of the Sacramento River basin: implications for conservation of native fishes in the Central Valley, California. Environmental Biology of Fishes 63:373-388.

McEwan, D. R. 2001. Central Valley steelhead. *In* R. L. Brown (ed.), Department of Fish and Game Fish Bulletin 179: Contributions to the Biology of Central Valley Salmonids, vol. 1, p. 1–43. California Department of Fish and Game, Sacramento.

Meng, L, Matern, SA. 2001. Native and introduced larval fishes of Suisun Marsh, California: the effects of freshwater flow. Transactions of the American Fisheries Society 130:750-765.

Mesick, C. 2001. The effects of San Joaquin River flows and Delta export rates during October on the number of adult San Joaquin Chinook salmon that stray, p. 139-162 in Brown, R (ed), Department of Fish and Game Fish Bulletin 179, Contributions to the biology of Central Valley salmonids, volume 2.

Miller, WJ. 2011. Revisiting assumptions that underlie estimates of proportional entrainment of delta smelt by State and Federal water diversions from the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 9: Issue 1 [April 2011], article 5.

Monismith, S.G., J.L. Hench, D.A. Fong, N.J. Nidzieko, W.E. Fleenor, L.P. Doyle, and S.G. Schladow. 2009. Thermal variability in a tidal river. Estuaries and Coasts 32: 100–110.

Monsen, NE, Cloern, JE, Burau, JR. 2007. Effects of flow diversions on water and habitat quality: examples from California's highly manipulated Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 5: Issue 3 [July 2007], article 2.

Moyle, P.B., R. D. Baxter, T. Sommer, T. C. Foin, and S. A. Matern. 2004. Biology and population dynamics of Sacramento Splittail (*Pogonichthys macrolepidotus)* in the San Francisco Estuary: a review. San Francisco Estuary and Watershed Science [online serial] 2(2):1-47. *http://repositories.cdlib.org/jmie/sfews/*

Moyle, PB, Bennett, WA. 2008. The future of the Delta ecosystem and its fish. Technical Appendix D, in Lund, J, Hanak, E, Fleenor, W, Bennett, W, Howitt, R, Mount, J, Moyle, P. Comparing futures for the Sacramento-San Joaquin Delta. San Francisco, CA: Public Policy Institute of California.

Moyle, PB, Crain, PK, Whitener, K, Mount, JF. 2003. Alien fishes in natural streams: fish distribution, assemblage structure, and conservation in the Cosumnes River, California, U.S.A. Environmental Biology of Fishes 68:143-162.

Moyle, PB. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkeley, CA.

Newman, KB, Rice, J. 2002. Modeling the survival of Chinook salmon smolts outmigrating through the lower Sacramento River system. Journal of the American Statistical Association 97:983-993.

Newman, KB. 2003. Modelling paired release-recovery data in the presence of survival and capture heterogeneity with application to marked juvenile salmon. Statistical Modelling 3:157-177.

Newman, KB. 2008. An evaluation of four Sacramento-San Joaquin River Delta juvenile salmon survival studies. In support of CALFED Science Program Grant Sci-06-G06-299. March 31, 2008.

Newman and Brandes. 2010. Hierarchical modeling of juvenile chinook salmon survival as a function of Sacramento-San Joaquin Delta water exports. North American Journal of Fisheries Management. 30. 157-169.

Nichols, FH, Thompson, JK, Schemel, LE. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. II. Displacement of a former community.

NMFS (National Marine Fisheries Service). 2009. NMFS Biological and Conference Opinion on the long-term operation of the Central Valley Project and State Water Project.

Nobriga, ML, Feyrer, F, Baxter, RD, Chotkowski, M. 2005. Fish community ecology in an altered river delta: spatial patterns in species composition, life history strategies and biomass. Estuaries 28:776-785.

Nobriga, ML, Sommer, TR, Feyrer, F, Fleming, K. 2008. Long-term trends in summertime habitat suitability for delta smelt, *Hypomesus transpacificus*. San Francisco Estuary and Watershed Science 6: Issue 1 [February 2008], article 1.

Odeh M, JF Noreika, A Haro, A Maynard, T Castro-Santos, and GF Čada. 2002. Evaluation of the Effects of Turbulence on the Behavior of Migratory Fish. DOE/BP-00000022-1, prepared by the U.S. Geological Survey and Oak Ridge National Laboratory for the Bonneville Power Administration, Portland, Oregon.

Olden, JD, Poff, NL, Bestgen, KR. 2006. Life-history strategies predict fish invasions and extirpations in the Colorado River basin. Ecological Monographs 76:25-40.

Orsi, JJ, Mecum, WL. 1996. Food limitation as the probable cause of a long-term decline in the abundance of *Neomysis mercedis* the oppossum shrimp in the Sacramento-San Joaquin estuary. Pages 375-401 in Hollibaugh, JT (ed), San Francisco Bay: the ecosystem. American Association for the Advancement of Science, San Francisco.

Perry, R. W., J. R. Skalski, P. L. Brandes, P. T. Sandstrom, A. P. Klimley, A. Ammann, and B. MacFarlane. 2010.

Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River Delta. North American Journal of Fisheries Management 30:142-156.

Poytress, W.R., J.J. Gruber, D.A., Trachtenbarg, and J.P. Van Eenennaam. 2009. 2008 Upper Sacramento River green sturgeon spawning habitat and larval migration surveys. Annual Report of U.S. Fish and Wildlife Service to US Bureau of Reclamation, Red Bluff, CA.

Quist, MC, Hubert, WA, Rahel, FJ. 2004. Relations among habitat characteristics, exotic species, and turbid-river cyprinids in the Missouri River drainage of Wyoming. Transactions of the American Fisheries Society 133:727-742.

Radtke, LD. 1966. Distribution of smelt, juvenile sturgeon, and starry flounder in the Sacramento-San Joaquin Delta with observations on the food of sturgeon. Pages 115-126 in: Ecological Studies of the Sacramento-San Joaquin Delta. PartCalif. Fish Game, Fish. Bull. 13

Rodríguez, MA, Lewis, WM, Jr. 1997. Stucture of fish assemblages along environmental gradients in floodplain lakes of the Orinoco River. Ecological Monographs 67:109-128.

Rosenfield, JR, and C. Swanson. 2010. Regarding flow criteria for the delta necessary to protect public trust resources: delta outflows. Exhibit TBI-2 to the State Water Resouces Control Board. (http://www.bay.org/publications/flow-criteria-for-the-delta-ecosystem)

Rosenfield, JA, Baxter, RD. 2007. Population dynamics and distribution patterns of longfin smelt in the San Francisco Estuary. Transactions of the American Fisheries Society 136:1577-1592.

Sattherthwaite, WH, Beakes, MP, Collins, EM, Swank, DR, Merz, JE, Titus, RG, Sogard, SM, Mangel, M. 2010. State-dependent life history models in a changing (and regulated) environment: steelhead in the California Central Valley. Evolutionary Applications 3:221-243.

Schoellhamer, DH. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34: DOI 10.1007/s12237-011-9382-x.

Seesholtz, A, Cavallo, BJ, Kindopp, J, Kurth, R. 2004. Juvenile fishes of the lower Feather River: distribution, emigration patterns, and associations with environmental variables. American Fisheries Society Symposium 39:141-166.

Sommer, T, Armor, C, Baxter, R, Breuer, R, Brown, L, Chotkowski, M, Culberson, S, Feyrer, F, Gingras, M, Herbold, B, Kimmerer, W, Mueller-Solger, A, Nobriga, M, Souza, K. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32(6):270-277.

Sommer, TR, Harrell, WC, Mueller-Solger, A, Tom, B, Kimmerer, W. 2004. Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. Aquatic Conservation: Marine and Freshwater Ecosystems 14:247-261.

Sommer, T, Harrell, B, Nobriga, M, Brown, R, Moyle, P, Kimmerer, W, Schemel, L. 2001. California's Yolo Bypass: evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26(8):6-16.

Sommer, TR, Baxter, R, Herbold, B. 1997. Resilience of splittail in the Sacramento-San Joaquin estuary. Transactions of the American Fisheries Society 126:961-976.

Sommer, TR, Harrell, WC, Nobriga, ML. 2005. Habitat use and stranding risk of juvenile Chinook salmon on a seasonal floodplain. North American Journal of Fisheries Management 25:1493-1504.

Sommer, TR, Nobriga, ML, Harrell, WC, Batham, W, Kimmerer, WJ. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58:325-333.

Stevens, DE, Miller, LW. 1983. Effects of river flow on abundance of young Chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin river system. North American Journal of Fisheries Management 3:425-437.

Stewart, AR, Luoma, SN, Schlekat, CE, Doblin, MA, Hieb, KA. 2004. Foodweb pathway determines how selenium affects aquatic ecosystems: a San Francisco Bay case study. Environmental Science and Technology 38:4519-4526.

Sweetnam, DA. 1999. Status of delta smelt in the Sacramento-San Joaquin Estuary. California Fish and Game 85:22-27.

Thomson, JR, Kimmerer, WJ, Brown, LR, Newman, KB, Mac Nally, R, Bennett, WA, Feyrer, F, Fleishman, E. 2010. Bayesian change-point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications 20:1431-1448.

U.S. Fish and Wildlife Service. 1995b. Working paper on restoration needs: habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volume 3. May 9, 1995. Prepared for the U.S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group.

USFWS (United States Fish and Wildlife Service). 2008. Formal Endangered Species Act consultation on the proposed coordinated operations of the Central Valley Project (CVP) and State Water Project (SWP).

USFWS (United States Fish and Wildlife Service). 2011. Declaration of Matthew L. Nobriga in support of Federal Defendents' opposition to Plaintiffs' motion for injunctive relief, Case 1:09-cv-00407-OWW-DLB.

Wagner, W., Stacey, M., Brown, L., and Dettinger, M., 2011. Statistical models of temperature in the Sacramento-San Joaquin Delta under climate-change scenarios and ecological implications: Estuaries and Coasts, v. 34, no. 3, p. 544-556., doi:10. 1007/s12237-010-9369-z. (on-line abstract or on-line article in pdf format, 595 KB, published by Springer with open access

Wilkerson, FP, Dugdale, RC, Hogue, VE, Marchi, A. 2006. Phytoplankton blooms and nitrogen productivity in San Francisco Bay. Estuaries and Coasts 29:401-416.

Williams, JG. 2006. Central Valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science 4: Issue 3 [December 2006], article 2.

Winder, M, Jassby, AD, Mac Nally, R. 2011. Synergies between climate anomalies and hydrological modifications facilitate estuarine biotic invasions. Ecology Letters: doi: 10.1111/j.1461-0248.2011.011635.x.

Wright, SA, Schoellhamer, DH. 2004. Trends in the sediment yield of the Sacramento River, California, 1957-2001. San Francisco Estuary and Watershed Science 2: http//repositories.cdlib.org/jmie/sfews/vol2/iss2/art2.